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HIV PROTEASE INHIBITORS

*Jens E17* Specification  
*Jens B'7*

Field of Invention:

The invention relates to HIV and FIV protease inhibitors. More particularly, the invention is directed to combinatorial libraries of HIV and FIV protease inhibitors characterized by  $\alpha$ -keto amide or hydroxyethylamine core structures flanked by on one side by substituted pyrrolidines, piperidines, or azasugars and on the other side by phenylalanine, tyrosine, or substituted tyrosines. The invention is also directed to methods for making such libraries, to the disclosed compounds made by such method, and to a method for screening such libraries for identifying candidate drugs which have clinically useful activity and which are potentially resistive against loss of inhibitory activity due to development of resistant strains of HIV.

20 Statement of Government Rights:

This invention was made with government support under National Institutes of Health Grants No.GM 48870 and No. GM 44154 and NCI, DHHS, contract No. N01-CO-46000. The U.S. government has certain rights in the invention.

25 Background:  
Human immunodeficiency virus protease (HIV PR) is an important target for the inhibition of viral replication. Though many potent *in vitro* inhibitors have been developed, most of them are either inactive

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or toxic *in vivo*, or mutant forms of the virus emerge which are resistant. (See J.H. Condra, et al., *Nature* (1995): vol. 374, 569-571; M. Markowitz, et al., *J. Virol.* (1995): vol. 69, 701; D. J. Kempf, et al., *Proc. Natl. Acad. Sci. USA* (1995): vol. 92, 2484-2488; A.K. Ghosh, et al., *J. Med. Chem.* (1994): vol. 37, 2506-2508; P.Y. Lam, et al., *Science* (1994): vol. 263, 380-384; N.A. Roberts, et al., *Science* (1990): vol. 248, 358; and E.E. Kim, et al., *J. Am. Chem. Soc.* (1995): vol. 117, 1181-1182.)

The lack of animal systems to test the efficacy of the inhibitors further slows down the drug development process. Recently a similar protease has been identified in the life cycle of feline immunodeficiency virus (FIV). (R.L. Talbott, et al., *Proc. Natl. Acad. Sci. USA* (1989): vol. 86, 5743-5747; and N.C. Pedersen, et al. *Science* (1987): vol. 235, 790-793.) FIV is a virus which leads to clinical symptoms comparable to those observed in human acquired immune deficiency syndrome (AIDS). Studies have shown that up to 14% of the cats surveyed in the USA and Canada are infected with FIV. (J.K., Yamamoto, et al., *JAVMA* (1989): vol. 194, 213-220.) In Japan, the figure is 28.9%. (T. Ishida, et al., *JAVMA* (1989): vol. 194, 221-225.)

In drug resistant mutants of HIV, there are at least six cases where HIV PR residues mutate to the structurally aligned residue found in FIV PR. The amino acid changes in HIV PR are V32I (I37-FIV), L90M (M107-FIV), N88D (D105-FIV), I50V (V59'-FIV), K20I

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(I25-FIV), and Q29K (K109-FIV). For a list of resistant HIV PR mutants is disclosed by J. W. Mellors, et al. (*International Antiviral News* (1995): vol. 3, 8-13.) The structure alignment was derived from the X-ray crystal structure of FIV PR solved by A. Wlodawer (reference 36). Superimposition of the two proteases based on their X-ray structures indicates similarities between the two proteases and the drug resistant HIV proteases.

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HIV PR is a 99 amino acid aspartyl protease which functions as a homodimer. (M.A. Navia, et al., *Nature* (1989): vol. 337, 615-620; and D.D. Loeb, *Virol.*

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(1989): vol. 63, 111-121.) FIV PR is also a homodimeric aspartyl protease which consists of 116 amino acid residues. (J.H. Elder, *Infectious Agents and Disease* (1994): vol. 2, 361-374.) Both HIV and FIV proteases are responsible for the processing of viral gag and gag-pol polyproteins into structural proteins and enzymes essential for the proper assembly and maturation of full infectious virions. (S.K.

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Thompson, *Bioorg. Med. Chem. Lett.* (1994): vol. 4, 2441-2446.) In particular HIV and FIV proteases show high specificity for the selective cleavage of the

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Tyrosine/Phenylalanine-Proline amide bonds in the Matrix-Capsid domain of the gag-pol polyproteins, a specificity not exhibited by mammalian cellular proteases which are not known to efficiently hydrolyze peptide bonds involving the proline

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nitrogen. (C. Debouck, *Aids Research and Human Retroviruses* (1992): vol. 8, 153-164; and J.H. Elder, *J. Virol.* (1993): vol. 67, 1869-1876.) It is this

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specificity that makes HIV PR an attractive target for inhibition. A comparison of the amino acid sequence about the matrix capsid cleavage site (Tyrosine ~ Proline bond) in both HIV and FIV is provided below. As can be seen the residues about the cleavage site are the same at four positions, P<sub>3</sub>, P<sub>1</sub>, P<sub>1'</sub>, and P<sub>2'</sub>. It is disclosed herein that, due to these similarities, certain HIV PR inhibitors also inhibit FIV PR.

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	P <sub>4</sub>	P <sub>3</sub>	P <sub>2</sub>	P <sub>1</sub>		P <sub>1'</sub>	P <sub>2'</sub>	P <sub>3'</sub>	P <sub>4'</sub>
HIVPR	Ser	Gln	Asn	Tyr	~	Pro	Ile	Val	Gln
FIVPR	Pro	Gln	Ala	Tyr	~	Pro	Ile	Gln	Thr

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Activated ketones, in general, have been shown to inhibit most kinds of proteases (Barrett et. al., *Proteinase Inhibitors*; Research monographs in cell and tissue physiology; Dingle, J. T., Gordon, J.L., General Eds.; Elsevier Science Publishers; Amsterdam, 1986).

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In particular, a recent study shows the design of three different classes of activated ketones which inhibit the aspartyl protease, renin. These potent analogs display IC<sub>50</sub> values from 4000 nM to 4.1 nM and include 1,1,1-trifluoromethyl ketones,  $\alpha$ -keto esters, and  $\alpha$ -diketones as the activated ketone functionalities (Patel et. al. *J. Med Chem.* 1993, 36, 2431).

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The  $\alpha$ -keto-amide core structure is isosterically analogous to the activated ketones but is more potent than the reported hydroxyethylamine or phosphinic acid HIV protease inhibitors that are mechanism-based

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isosteric core structures.

The  $\alpha$ -keto-amide core structure has been used in  
inhibitors of various enzymes which include serine  
5 and cysteine proteases, hydrolases and  
aminopeptidases. As an example, a series of  
dipeptidyl and tripeptidyl  $\alpha$ -keto amides have been  
synthesized and evaluated as potent inhibitors for  
cysteine proteases which include enzymes calpain I,  
10 calpain II, cathepsin B, and papain (Li et. al. *J. Med. Chem.* 1993, 36, 3472). Another study has  
identified  $\alpha$ -keto amide analogs as inhibitors of an  
epoxide hydrolase (Wong et. al. *J. Med. Chém.* 1993,  
15 36, 211). Additionally, the inhibition of arginyl  
aminopeptidase ( $K_i = 1.5 \mu M$ ), cytosol aminopeptidase  
( $K_i = 1.0 \mu M$ ) and microsomal aminopeptidase ( $K_i = 2.5 \mu M$ )  
has been observed from  $\alpha$ -keto amide analogs which  
can be derived from 3-amino-2-oxo-4-phenylbutanoic  
acid amides. (Rich et. al. *J. Med Chem.* 1992, 35,  
20 451).

The activity of dipeptide isosteres is often  
enhanced by addition of amino acid residues to either  
the N and C-terminus of the isostere to improve  
25 binding in the active site. The prior art provides  
examples of such inhibitors which include renin,  
aspartyl proteases and procine pepsin inhibitors  
(Rich et. al. *J. Med Chem.* 1992, 35, 451). The  
resulting inhibitors generally exhibit high binding  
30 affinity to HIV protease. They display, however,  
instability and/or poor oral bioavailability.

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The related art has provided examples of  $\alpha$ -keto amide inhibitors of aminopeptidases which contain an unsubstituted proline moiety in the molecule. In particular, Gordon and co-workers have described  $\alpha$ -keto amide inhibitors with an unsubstituted proline ring for the metalloprotease angiotensin converting enzyme (ACE) (Gordon et. al. *Biochem. Biophys. Res. Commun.* 1984, 124, 141). Additionally, Arai et. al. (*Chem. Pharm. Bull.* 41, 9, 1583) have reported potent inhibitory activity by a prolyl endopeptidase (PEP) inhibitor (N-[N-(4-phenylbutanoyl)-L-prolyl]pyrrolidine).

What is needed are combinatorial libraries of HIV and FIV protease inhibitors and simple synthetic methods for making same.

What is needed is a class of HIV and FIV protease inhibitor having enhanced possibilities of variability at the P<sub>1</sub> and P<sub>1'</sub> positions for improving the binding between the enzyme and its inhibitor.

What is needed are methods for screening combinatorial libraries of HIV and FIV protease inhibitors for identifying candidates having both clinically useful inhibitory activity and a potential resistivity to a loss of inhibitory activity due to development of resistant strains of HIV.

What is needed are new HIV and FIV protease inhibitors having clinically useful inhibitory activity and a resistivity to a loss of inhibitory activity due to development of resistant strains of

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HIV.

Summary:

5 It is disclosed herein that FIV PR provides a good model of drug resistance in retroviral proteases. Testing candidate drugs with respect to their inhibitory activity against both HIV and FIV proteases and determining which inhibitors are simultaneously efficacious against both of these mechanistically identical proteases, identifies inhibitors of HIV protease which are potentially less prone to resistance development. Candidate drugs which are successfully screened *in vitro* may then be tested in cats as model systems on which to test HIV PR inhibitors *in vivo*.

20 Accordingly, one aspect of the invention is directed to a method for identifying a drug candidate as an HIV protease inhibitor potentially resistive against loss of inhibitory activity due to development of resistant strains of HIV. The method employs the following steps:

25 Step A: determining whether the drug candidate has a binding activity with respect to HIV protease of less than 1  $\mu$ M;

Step B: determining whether the drug candidate has an inhibitory activity with respect to HIV protease of less than 1  $\mu$ M;

30 Step C: determining whether the drug candidate has a binding activity with respect to FIV protease of less than 1  $\mu$ M; and

Step D: determining whether the drug candidate has

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an inhibitory activity with respect to FIV protease of less than 1  $\mu$ M.

If the drug candidate is determined to have binding and inhibitory activities with respect to both HIV protease and FIV protease of less than 1  $\mu$ M in each of the above steps, then the drug candidate is selected as an HIV protease inhibitor potentially resistive against loss of inhibitory activity due to development of resistant strains of HIV.

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The above method may be applied either to individual drug candidates or to a library of drug candidates.

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Another aspect of the invention is directed to methods for synthesizing drug candidates which potentially inhibit HIV protease. More particularly, the drug candidates are of a type which include an N-terminus, a C-terminus, and an  $\alpha$ -keto amide core structure linking the N-terminus and the C-terminus.

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The N-terminus includes an aromatic amino acid residue selected from the group consisting of phenylalanine, tyrosine, and O-substituted tyrosines. The aromatic amino acid includes a carbonyl group for linking to

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and incorporation into the  $\alpha$ -keto amide core structure. The C-terminus includes a heterocyclic ring having a ring nitrogen and one or more substitutions. The ring nitrogen of the C-terminus

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is linked to and incorporated into the  $\alpha$ -keto amide core structure. The synthetic method includes the following step:

Step A: providing an N-terminus precursor identical to the N-terminus except that the

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carbonyl group is replaced by an  $\alpha$ -hydroxyl acid group;

Step B: providing a C-terminus precursor identical to the C-terminus except that the ring nitrogen forms a secondary amine;

5 Step C: coupling the N-terminus precursor of step A to the C-terminus precursor of step B to form a drug candidate precursor identical to the drug candidate except that the  $\alpha$ -keto amide core structure of the drug candidate is replaced by an  $\alpha$ -hydroxyl amide core structure linking and incorporating the carbonyl group of the N-terminus and the ring nitrogen of the C-terminus; and then

10 15 Step D: oxidizing the  $\alpha$ -hydroxyl amide core structure of the drug candidate precursor of step C for forming the  $\alpha$ -keto amide core structure and the drug candidate.

20 The above synthetic method may also be adapted for synthesizing combinatorial libraries of HIV and FIV protease inhibitors containing  $n \times m$  drug candidates. The above synthetic method is modified by providing  $n \times m$  reaction vessels, loading each of the  $n$  N-terminus precursors into  $m$  of the reaction vessels, and then loading each of the  $m$  C-terminus precursors into  $n$  of reaction vessels so as to form  $n \times m$  admixtures of N-terminus precursor and C-terminus precursors. Then, each of the  $n \times m$  admixtures is allowed to undergo a coupling reaction in which the N-terminus precursor couples to the C-terminus precursor to form  $n \times m$  drug candidate precursors. The drug precursor candidates are identical to the  $n \times m$

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drug candidates except that the  $\alpha$ -keto amide core structure of the  $n \times m$  drug candidates is replaced by an  $\alpha$ -hydroxyl amide core structure linking and incorporating the carbonyl group of the N-terminus and the ring nitrogen of the C-terminus. Finally, the  $\alpha$ -hydroxyl amide core structure of each of the  $n \times m$  drug candidate precursors is oxidized so as to form the  $\alpha$ -keto amide core structure of the desired drug candidate.

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A further aspect of the invention is directed to combinatorial libraries  $n \times m$  drug candidates characterized by having a  $\alpha$ -keto amide core structure and a potential inhibitory activity with respect to HIV protease. The drug candidates are characterized by having an N-terminus selected from  $n$  N-termini where  $n$  is two or greater, a C-terminus selected from  $m$  C-termini where  $m$  is two or greater, and a  $\alpha$ -keto amide core structure which links the N-terminus to the C-terminus. Each of the  $n$  N-termini includes an aromatic amino acid residue selected from the group consisting of phenylalanine, tyrosine, and O-substituted tyrosine. The aromatic amino acid includes a hydroxyethyl group in lieu of a carbonyl group which is linked to and incorporated into the  $\alpha$ -keto amide core structure. Each of the  $m$  C-termini includes a heterocyclic ring having a ring nitrogen and one or more substitutions. The ring nitrogen of the C-terminus is linked to and is incorporated into the  $\alpha$ -keto amide core structure.

Another aspect of the invention is directed to combinatorial libraries of  $n \times m$  drug candidates

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characterized by having a hydroxyethylamine core structure and a potential inhibitory activity with respect to HIV protease. The drug candidates are characterized by having an N-terminus selected from  $n$  N-termini where  $n$  is two or greater, a C-terminus selected from  $m$  C-termini where  $m$  is two or greater, and a hydroxyethylamine core structure which links the N-terminus to the C-terminus. Each of the  $n$  N-termini includes an aromatic amino acid residue selected from the group consisting of phenylalanine, tyrosine, and O-substituted tyrosine. The aromatic amino acid includes a hydroxyethyl group in lieu of a carbonyl group which is linked to and incorporated into the hydroxyethylamine core structure. Each of the  $m$  C-termini includes a heterocyclic ring having a ring nitrogen and one or more substitutions. The ring nitrogen of the C-terminus is linked to and is incorporated into the hydroxyethylamine core structure.

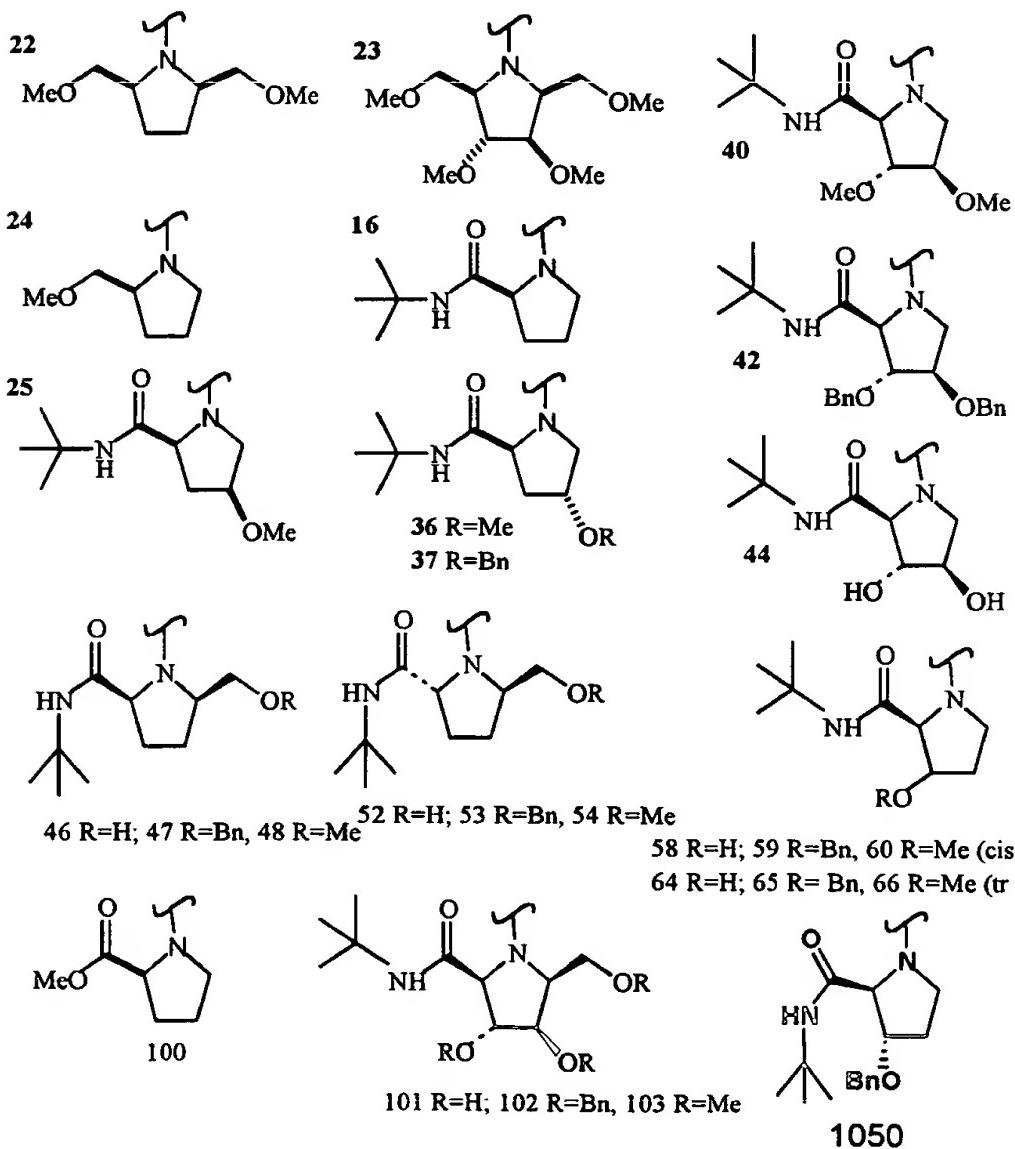
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Another aspect of the invention is directed to a series of improved mechanism based inhibitor of HIV or FIV aspartyl protease. Each of the improved mechanism based inhibitors is of a type having an N-terminus, a C-terminus, and a core structure for linking the N-terminus to the C-terminus. The N-terminus includes an aromatic amino acid residue linked to the core structure. The C-terminus includes a heterocyclic ring having a ring nitrogen linked to the core structure. The core structure is isosteric with a scissile amide bond of an HIV or FIV aspartyl protease substrate.

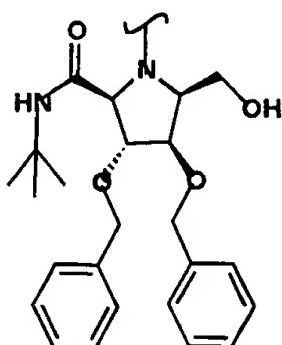
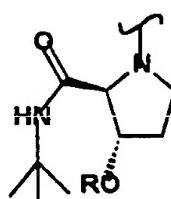
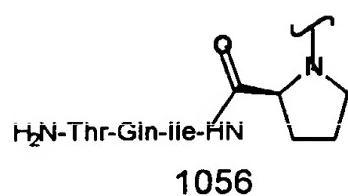
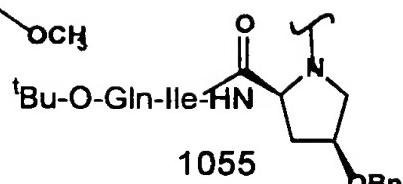
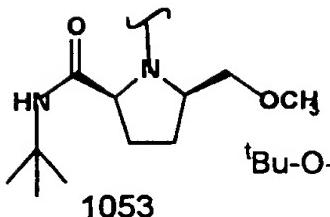
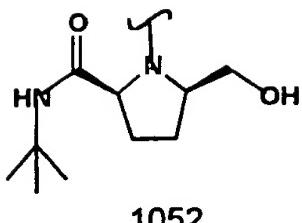
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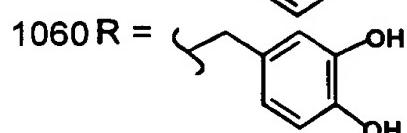
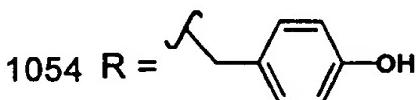
In the first embodiment of improved mechanism based inhibitor, the core structure is an  $\alpha$ -keto amide and the heterocyclic ring of the N-terminus is a pyrrolidine having at least one substituent other than carboxylic acid and carboxymethyl ester. Examples of this first embodiment of improved mechanism based inhibitors are provided as follows:



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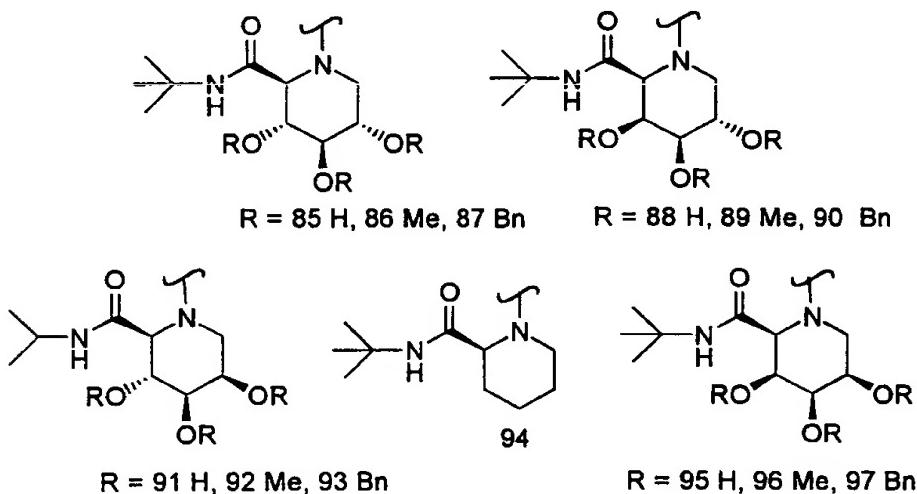


where:



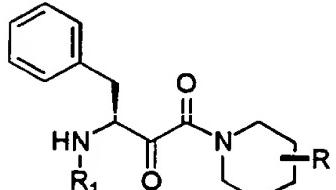
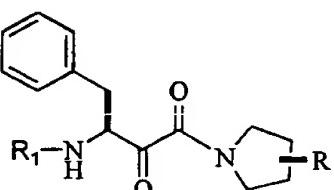
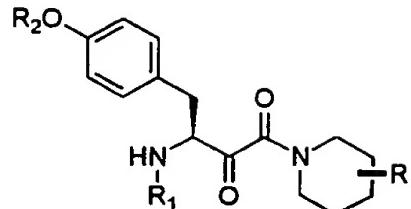
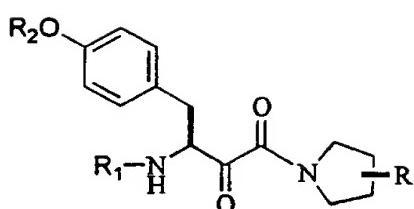
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In a second embodiment of improved mechanism based inhibitor, the core structure is an  $\alpha$ -keto amide and the heterocyclic ring of the N-terminus is a piperadine or azasugar. Examples of piperadines and azasugars employed in this second embodiment of improved mechanism based inhibitors are provided as follows:



In a third embodiment of improved mechanism based inhibitor, the core structure is an  $\alpha$ -keto amide and the aromatic amino acid of the C-terminus is selected from a group consisting of tyrosine having a protected amino, tyrosine having a protected amino and a substituted hydroxyl, and phenylalanine having a protected amino protected by carbobenzyloxy. Examples of this third embodiment of improved mechanism based inhibitors are provided as follows:

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wherein R is selected from the group consisting of hydrogen, hydroxy, benzyloxy, alkyl<sub>(c1-c4)</sub>-oxy, o-methoxy-benzyloxy, m-methoxy-benzyloxy, p-methoxy-benzyloxy, o-methoxy-nitrobenzyloxy, m-methoxy-nitrobenzyloxy, p-methoxy-nitrobenzyloxy, acetonide, benzylidene, 3-oxymethyl-catechol, 4-oxymethyl-catechol; R<sub>1</sub> is selected from the group consisting of carbobenzyloxy (CBZ), tert-butoxycarbonyl (t-BOC), acyl; R<sub>2</sub> is selected from the group consisting of hydrogen, benzyl, alkyl<sub>(c1-c4)</sub>, o-methoxy-benzyl, m-methoxy-benzyl, p-methoxy-benzyl, o-methoxy-nitrobenzyl, m-methoxy-nitrobenzyl, p-methoxy-nitrobenzyl, 3-methylene-catechol, 4-methylene-catechol.

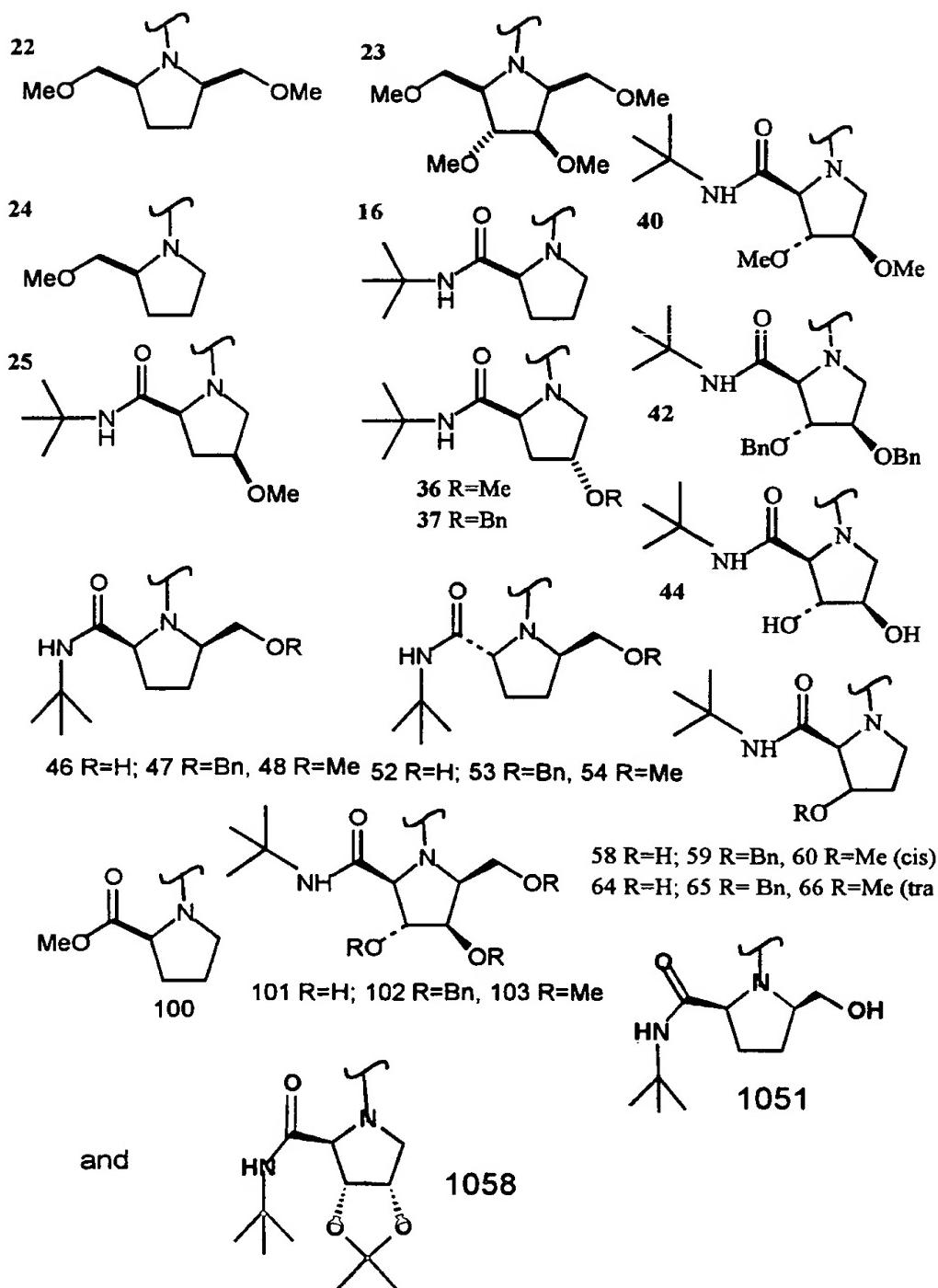
In a fourth embodiment of improved mechanism based inhibitor, the core structure is an

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hydroxyethylamine and the heterocyclic ring of the N-terminus is a pyrrolidine having at least one substituent other than carboxylic acid and carboxymethyl ester. Examples of pyrrolidines employed in this fourth embodiment of improved mechanism based inhibitors are provided as follows:

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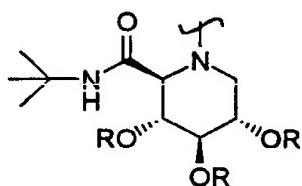
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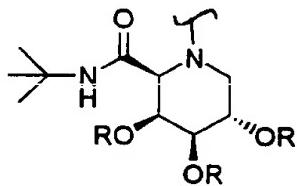
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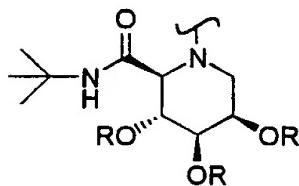
In a fifth embodiment of improved mechanism based inhibitor, the core structure is hydroxyethylamine and the heterocyclic ring of the N- terminus is a piperadine or azasugar. Examples of piperadines and azasugars employed in this fifth embodiment of improved mechanism based inhibitors are provided as follows:



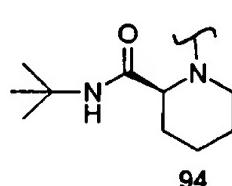
R = 85 H, 86 Me, 87 Bn



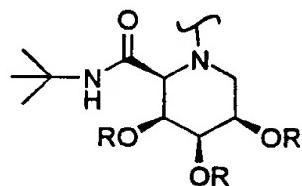
R = 88 H, 89 Me, 90 Bn



R = 91 H, 92 Me, 93 Bn



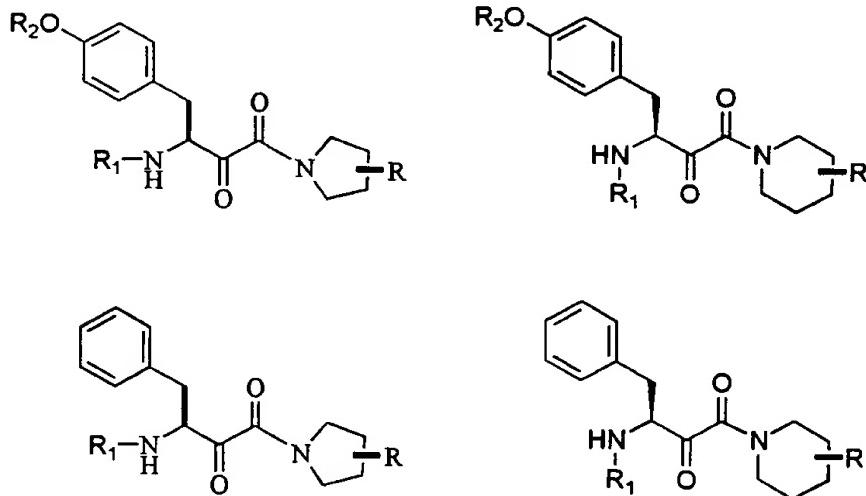
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R = 95 H, 96 Me, 97 Bn

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In a sixth embodiment of improved mechanism based inhibitor, the core structure is hydroxyethylamine and the aromatic amino acid of the C-terminus is selected from a group consisting of tyrosine having a protected amino, tyrosine having a protected amino and a substituted hydroxyl, and phenylalanine having a protected amino protected by carbobenzyloxy. Examples of this sixth embodiment of improved mechanism based inhibitors are provided as follows:



wherein R is selected from the group consisting of hydrogen, hydroxy, benzyloxy, alkyl<sub>(c1-c4)</sub>-oxy, o-methoxy-benzyloxy, m-methoxy-benzyloxy, p-methoxy-benzyloxy, o-methoxy-nitrobenzyloxy, m-methoxy-nitrobenzyloxy, p-methoxy-nitrobenzyloxy, acetonide,

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benzylidene, 3-oxymethyl-catechol, 4-oxymethyl-catechol; R<sub>1</sub> is selected from the group consisting of carbobenzyloxy (CBZ), tert-butoxycarbonyl (*t*-BOC), acyl; R<sub>2</sub> is selected from the group consisting of 5 hydrogen, benzyl, alkyl<sub>(c1-c4)</sub>, o-methoxy-benzyl, m-methoxy-benzyl, p-methoxy-benzyl, o-methoxy-nitrobenzyl, m-methoxy-nitrobenzyl, p-methoxy-nitrobenzyl, 3-methylene-catechol, 4-methylene-catechol.

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Description of Figures

Figure 1 illustrates an approach to rapidly access a number of potential inhibitors of HIV and/or FIV proteases to determine the protecting group and ideal substitution pattern of the 'proline' moiety to provide maximum inhibition of the enzymes.

Figure 2 illustrates a comparison of the  $\alpha$  keto amide core structure to other isosteric structures. Compound activities are indicated.

Figure 3 illustrates hydrogen bond interactions between a hydroxyethylamine isostere and the active site of HIV PR as observed from X-ray crystallography.

Figure 4 illustrates a general acid - base mechanism for inhibitor 2 interaction with HIV PR aspartate groups.

Figure 5 illustrates inhibitory activity of variously substituted pyrrolidine analogues against

HIV PR.

Figure 6 illustrates the synthesis of compound  
11. The steps indicated are as follows: (i) *t*-BuLi,  
5 ethyl vinyl ether, MgBr<sub>2</sub>, THF; (ii) O<sub>3</sub>, CH<sub>2</sub>Cl<sub>2</sub>; (iii)  
0.17N LiOH, MeOH/H<sub>2</sub>O, 2:1, 98%.

Figure 7 illustrates the synthesis of compound  
2. The steps indicated are as follows: (i) NaBH<sub>4</sub>,  
10 MeOH, 0 °C, 95%; (ii) 0.17 N LiOH, MeOH/H<sub>2</sub>O, 2:1,  
98%; (iii) EDC, HOBT, DIEA, DMF/CH<sub>3</sub>CN, (1:1), 84%;  
(iv) Dess-Martin periodinane, CH<sub>2</sub>Cl<sub>2</sub>, 95%.

Figure 8 illustrates the synthesis of compound  
15 3. The steps are indicated as follows: (i) EDC,  
HOBT, DIEA, DMF/CH<sub>3</sub>CN, (1:1), 80%; (ii) Dess-Martin  
periodinane, CH<sub>2</sub>Cl<sub>2</sub>, quantitative.

Figure 9 illustrates the synthesis of compounds  
20 31 and 32 with the indicated substrate and reagents.

Figure 10 illustrates the synthesis of compound  
35 with the indicated substrate and reagents.

25 Figure 11 illustrates a general coupling  
procedure to form hydroxyethyl amine compounds  
starting from epoxide 21 and using the indicated  
pyrrolidines. The procedure is as follows: (i)  
Methanol, Et<sub>3</sub>N, reflux, 24 hours, 40-60%.

30 Figure 12 illustrates a general coupling  
procedure to form  $\alpha$ -ketoamide compounds starting from

carboxyacid 15 and using the indicated pyrrolidines. The two step procedure is as follows: (i) EDC, HOBT, DIEA, DMF/CH<sub>3</sub>CN, (1:1); (ii) Dess-Martin periodinane oxidation, CH<sub>2</sub>Cl<sub>2</sub>, quantitative.

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Figure 13 illustrates a general coupling procedure to form  $\alpha$ -ketoamide compounds starting from carboxyacid 15 and using the indicated substituted piperidines. The two step procedure is as follows: (i) EDC, HOBT, DIEA, DMF/CH<sub>3</sub>CN, (1:1); (ii) Dess-Martin periodinane oxidation, CH<sub>2</sub>Cl<sub>2</sub>, quantitative.

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Figure 14 illustrates a general coupling procedure to form hydroxyethyl amine compounds starting from epoxide 21 and using the indicated substituted piperidines. The procedure is as follows: (i) Methanol, Et<sub>3</sub>N, reflux, 24 hours, 40-60%.

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Figure 15 illustrates the synthesis of pyrrolidines 46, 47 and 48 with the indicated substrate and reagents.

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Figure 16 illustrates the synthesis of pyrrolidines 52, 53 and 54 with the indicated substrate and reagents.

30

Figure 17 illustrates the synthesis of pyrrolidine 44 with the indicated substrate and reagents.

Figure 18 illustrates the synthesis of

pyrrolidine 40 with the following steps: (i) CBZ-Cl,  
methylene chloride; (ii) TBDPSCl, Et<sub>3</sub>N, DMF; (iii)  
Methyl iodide, sodium hydride, DMF; (iv) TBAF, THF;  
(v) 1.5 M H<sub>2</sub>SO<sub>4</sub>, CrO<sub>3</sub>, acetone; (vi) H<sub>2</sub>N<sup>t</sup>Bu, EDC,  
5 methylene chloride; (vii) H<sub>2</sub>, Pd(OH)<sub>2</sub> on Carbon, MeOH.

Figure 19 illustrates the synthesis of  
pyrrolidine 42 with the following steps: (i) BOC-ON,  
methylene chloride; (ii) TBDPSCl, Et<sub>3</sub>N, DMF; (iii)  
10 Benzyl bromide, sodium hydride, DMF; (iv) TBAF, THF;  
(v) 1.5 M H<sub>2</sub>SO<sub>4</sub>, CrO<sub>3</sub>, acetone; (vi) H<sub>2</sub>N<sup>t</sup>Bu, EDC,  
methylenec chloride; (vii) H<sub>2</sub>, Pd(OH)<sub>2</sub> on Carbon, MeOH.

Figure 20 illustrates the synthesis of  
15 pyrrolidines 58, 59, 60, 64, 65, and 66 with the  
following steps: For compounds 58, 59, 60: (i) CBZ-  
Cl, methylene chloride; (ii) TBDMSCl, Et<sub>3</sub>N, DMF; (iii)  
H<sub>2</sub>N<sup>t</sup>Bu, EDC, methylene chloride; (iv) TBAF, THF; (v)  
"Mitsunobu" procedure: PPh<sub>3</sub>, DEAD  
20 (diethylazaodicarboxylate), ClCH<sub>2</sub>CO<sub>2</sub>H, then water,  
pyridine to pH 6.7; (vi) Benzyl bromide for 59 or  
methyl iodide for 60, sodium hydride, DMF (omit this  
step for 58) (vii) H<sub>2</sub>, Pd(OH)<sub>2</sub> on Carbon, MeOH. For  
compounds 64, 65, and 66 same conditions as above  
25 without step (v) "Mitsunobu" procedure.

Figure 21 illustrates the synthesis of  
piperidines 86 and 87 with the following steps: (i)  
30 CBZ-Cl or BOC-ON, methylene chloride; (ii) TBDPSCl,  
Et<sub>3</sub>N, DMF; (iii) Benzyl bromide for 87 or methyl  
iodide for 86, sodium hydride, DMF (iv) TBAF, THF;  
(v) 1.5 M H<sub>2</sub>SO<sub>4</sub>, CrO<sub>3</sub>, acetone; (vi) H<sub>2</sub>N<sup>t</sup>Bu, EDC,  
methylenec chloride; (vii) H<sub>2</sub>, Pd(OH)<sub>2</sub> on Carbon, MeOH.

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Figure 22 illustrates the synthesis of piperidines 85 with the following steps: (i) CBZ-Cl or BOC-ON, methylene chloride; TBDPSCl, Et<sub>3</sub>N, DMF; (ii) acetic anhydride, triethylamine, DMF (iii) TBAF, THF; (iv) 1.5 M H<sub>2</sub>SO<sub>4</sub>, CrO<sub>3</sub>, acetone; (v) H<sub>2</sub>N<sup>t</sup>Bu, EDC, methylene chloride; (vi) NaOMe, MeOH; (vii) H<sub>2</sub>, Pd(OH)<sub>2</sub> on Carbon, MeOH.

Figure 23 illustrates tyrosine derivatives of pyrrolidine or piperidine containing  $\alpha$ -ketoamide and hydroxylethylamine core structures to probe for FIV and HIV protease selectivity.

Figure 24 illustrates targeted variable sites on the core structure which can be assessed using a combinatorial approach. Di-/tri-/tetrameric substrates for HIV-PR and FIV-PR are possible. Candidate molecules display activity by cleavage of either HIV-PR or FIV-PR protease. The candidate molecules are subsequently rederivatized via replacement of the scissile amide bond to an  $\alpha$ -keto amide or hydroxyethyl amine, affording further potential inhibitors. The synthetic strategy involves solution phase coupling of the added residues (standard coupling conditions, EDC HOBT, CH<sub>2</sub>Cl<sub>2</sub> or DMF) to afford di-/tri-/tetra peptides. Simple acidic and basic washes afford the desired peptides cleanly, with no purification necessary. Compounds are then dissolved in a minimal amount of DMSO and added to buffer solution, arranged in 96-well micro-titer plates. Addition of the enzyme and subsequent mass spectral analysis identifies the cleaved substrates as hits. These molecules are then

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rederivatized with an  $\alpha$ -keto amide or hydroxyethyl amine core unit and tested for inhibitory activity.

5       Figure 25 illustrates the creation of non-linear protease inhibitors using the up and down search for new complementary binding sites attached to a designed mechanism-based core structure.

10      Figure 26 illustrates various  $\alpha$ -ketoamide and hydroxyethyl HIV protease inhibitors.

15      Figure 27 illustrates the synthesis of  $\alpha$ -ketoamide compound 1050 with the indicated substrate and reagents.

20      Figure 28 illustrates the synthesis of hydroxyethylamine compound 1051 with the indicated substrate and reagents.

25      Figure 29 illustrates the synthesis of  $\alpha$ -ketoamide compound 1053 with the indicated substrate and reagents.

30      Figure 30 illustrates the synthesis of  $\alpha$ -ketoamide compounds 1054, 1059, and 1060 with the indicated substrates and reagents.

35      Figure 31 illustrates the synthesis of  $\alpha$ -ketoamide compound 1055 with the indicated substrate and reagents.

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Figure 32 illustrates the synthesis of  $\alpha$ -ketoamide compound 1056 with the indicated substrate and reagents.

5           Figure 33 illustrates the synthesis of  $\alpha$ -ketoamide compound 1057 with the indicated substrate and reagents.

Figure 34 illustrates the synthesis of  $\alpha$ -ketoamide compound 1058 with the indicated substrate and reagents.

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Detailed Description:

One aspect of the invention is directed to a new class of the HIV/FIV PR inhibitors, viz.  $\alpha$ -keto amide inhibitors. The mode of action of the  $\alpha$ -keto amide inhibitor is of particular interest as it represents a new type of mechanism-based enzyme inhibition which can lead to the development of tight-binding inhibitors to overcome the problem of resistance.

When assayed against HIV PR, the novel  $\alpha$ -keto amide 1 (Figure 3) was found to have a  $K_i$  of 6  $\mu\text{M}$ . Subsequent studies have shown that a simple modification of the N- and C-terminal protecting groups to give 2 (Figure 3) enhances the potency of this core isostere against HIV PR, to give a  $K_i$  of 214 nM.

The increase in activity in compound 2 may be due to favorable hydrophobic interactions between the protecting groups (i.e. the Cbz-protecting group and the t-Bu group) and the active site of HIV PR. The Boc-protecting group is also hydrophobic but is shorter and sterically more bulky, making it unable to extend effectively into the appropriate hydrophobic binding pocket. This result demonstrates how simple modifications of the core isostere can significantly improve its potency. It is disclosed that the potency of the  $\alpha$ -keto amide 2 can be improved by introduction of additional complementary groups to the proline ring moiety. Computer modeling (Insight/Discover) indicates that attachment of hydrophobic groups to the proline ring moiety will

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enhance binding. It is disclosed that addition of a *cis*-benzyl ether to C-4 of the proline moiety increased binding 3-fold ( $K_i = 65\text{nM}$ ).

5       The activity of the isostere 2 can be then compared to that of the identically substituted  $\alpha$ -hydroxy amide precursors 23 and 24. The *S*-diastereomer 24 ( $\text{IC}_{50} = 2\mu\text{M}$ ) is disclosed to be more potent than the *R*-diastereomer 23 ( $\text{IC}_{50} = 300 \mu\text{M}$ ), but  
10      less active than 2. The high potency of the  $\alpha$ -hydroxy amide 24 implies that the hydroxyl group is hydrogen bonding more effectively with the catalytic carboxylic acid groups of HIV PR than in compound 23, similar to that observed in the X-ray structure of a  
15      hydroxyethylamine inhibitor enzyme complex (Figure 4). The stereochemistry of the isosteres 23 and 24 was determined by  $^1\text{H}$  NMR studies on the *R*- and *S*-Mosher esters derived from the *S*- $\alpha$ -hydroxy ester 19.

20      The ketone moiety of the  $\alpha$ -keto amide 2 is disclosed to be hydrated and is hydrogen bonding in a similar manner to that of compound 23. However in this case,  $^{13}\text{C}$  NMR studies on compound 2 in deuterated DMSO/D<sub>2</sub>O (5:1) indicates that, in the presence of  
25      water, the ketone moiety of the  $\alpha$ -keto amide remains unhydrated even after incubation for 24 hours (Figure 5). This indicates that the ketone moiety of 2 is stable in the presence of water and is therefore difficult to hydrate in the absence of a catalyst.  
30      It is likely that hydration of the ketone moiety takes place within the active site of HIV PR as

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illustrated in Figure 6, and the resulting hydrate is then stabilized through hydrogen bonding interactions with the aspartate residues of the enzyme. The hydrated form of 2 is considered to be a good  
5 transition state mimic based on the model presented in Figure 6.

Time dependent assays do not exhibit time dependent inhibition, indicating that if the active  
10 form of the  $\alpha$ -keto amide 2 is indeed the hydrate, the hydration step must be rapid or 2 itself is the active form. To further investigate the mode of action, the X-ray structure of the complex between the  $\alpha$ -keto amide 2 and HIV PR was determined and the  
15 result indicated that the  $\alpha$ -keto amide is hydrated, supporting the enzyme-assisted hydration mechanism (Figure 7).

As seen in the electron density map, the  
20 inhibitor is bound in the active site of HIV-PR in its hydrated state (Figure 7). One of the two hydroxyls is located between two aspartates, making hydrogen bonds with both of them, while the other hydroxyl interacts with only one aspartate. The keto group is also hydrogen bonded to a catalytic  
25 aspartate. The phenylalanine and proline side chains occupy proper  $S_1$  and  $S_1'$  pockets making interactions similar to those observed in other structures. The carboxybenzyl group on the N-terminus and the tert-butyl group of the tert-butyl amide on the C-terminus of the inhibitor are roughly in the  $S_2$  and  $S_2'$ pockets, respectively. The conserved water (Wat-301), which

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is forming hydrogen bonds between the inhibitor and the two flaps of the enzyme, is clearly observed. Its location is rather asymmetric, unlike the case of the majority of other inhibitor complexes. The 5 distance between the carbonyl oxygen which mimics the P<sub>2</sub> CO group and Wat-301 is 2.5 Å, while the distance to the P<sub>1</sub>'CO is 3.2 Å.

Remarkable similarity is observed in the binding 10 mode of the central and C-terminal parts of compound 2, and the similar parts of an inhibitor KNI-272. The differences in their binding constants are very significant ( $K_i$  for KNI-272 is almost five orders of magnitude lower than for 2), despite the presence of 15 an extra hydrogen bond in the central part of the complex of HIV PR and compound 2. Thus the increase in the potency of KNI-272 must be due to the elongation of its N-terminus, which has a bulky 5-isoquinolyloxyacetyl (IQoa) moiety. The regions of 20 the protein interacting with this group, including the Phe-53 in one monomer and Pro-81 in another shift significantly towards the inhibitor, making extensive hydrophobic contacts with the IQoa group.

When the  $\alpha$ -keto amide 2 was tested against FIV PR, it was found to have no inhibitory effect when added in concentrations up to 70 mM. This result was surprising due to the similarity between the natural substrates for HIV and FIV proteases bordering the 25 matrix/capsid cleavage site as illustrated earlier. It appears that FIV PR may require additional specific residues between the P<sub>4</sub> - P<sub>4'</sub>sites, than HIV PR, before it is able to recognize the core isostere 30

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2 as a substrate. This is also supported by the observation that HIV PR will cleave an Acetyl-(6 residue) peptide substrate of sequence Gln-Ala-Tyr~Pro-Ile-Gln whereas the smallest peptide FIV PR 5 is known to cleave is an acetyl-(8 residue) peptide of sequence Pro-Gln-Ala-Tyr~Pro-Ile-Gln-Thr. The corresponding protected dipeptide (Cbz-Phe-Pro-NBu<sup>t</sup>) was not cleaved by HIV or FIV proteases under normal assay conditions.

10

In an effort to develop inhibitors of the FIV PR, it was found that the addition of suitable residues to interact with just the P<sub>2</sub>' and P<sub>3</sub>' sites of FIV PR was sufficient for moderate inhibition.

15

Coupling of a side chain specific for FIV PR to the C-terminus of 2 gave 4 (Figure 8). This extended isostere 4 was found to have an IC<sub>50</sub> of 25μM and a K<sub>i</sub> of 29 μM against FIV PR and the activity against HIV PR was slightly enhanced (K<sub>i</sub> of 154 nM). It appears

20

that the isosteric core structure of HIV PR inhibitors do not bind tightly to the FIV PR, and additional complementary groups are needed to enhance the binding. This difference is also observed in the analysis of other known HIV PR inhibitors. The

25

potent cyclic urea based HIV PR inhibitor DMP 323 (IC<sub>50</sub> = 36nM, K<sub>i</sub> = 0.27nM) for example was also found to be a very poor inhibitor of FIV PR (IC<sub>50</sub> = 7.3mM).

30

When the activity of the monomethylated derivative 7 is compared to that of the dimethylated derivative 5, it can be seen that a hydrophobic moiety at the C-5 position decreases the potency of the isostere, whereas the activity increases when

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similar hydrophobic substitutions are made at the C-3 and C-4 positions as in compound 6. The permethylated pyrrolidine derivative 6 was the most potent derivative of the series 5-7, but significant 5 activity was lost due to the absence of the amide bond at C-1, as can be seen by comparison of the activity of the methylated derivatives 5-7 to that of compound 8. The C-4 substituted pyrrolidine derivatives 9-11 were shown to be more potent than 8, 10 with the *trans*-C-4 methoxy derivative 10 being the best ( $IC_{50} = 2.9 \mu M$ ).

The permethylated  $\alpha$ -keto amide derivative 12 (Figure 10) was synthesized for comparison and was 15 found to be more potent than the corresponding hydroxyethylamine isostere 6 but significantly less potent ( $K_i = 20 \mu M$ ) than the original isostere 2 against HIV PR. This result again illustrates the importance of an amide bond at C-1 of the pyrrolidine 20 derivative.

In summary, a new class of mechanism based 25 inhibitors of the HIV and FIV proteases with pyrrolidine-containing  $\alpha$ -keto amide and hydroxyethylamine core structures is disclosed. These  $\alpha$ -keto amide core structure 2 are disclosed to be approximately 300-fold better than the corresponding hydroxyethylamine isosteric structure and 1300-fold better than the corresponding phosphinic acid derivative as an inhibitor of the HIV 30 protease. The  $\alpha$ -keto amide is however not hydrated until it is bound to the HIV protease as indicated by

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the NMR study and the X-ray structural analysis. Further analysis of the inhibition activities of hydroxyethylamine isosteres containing modified pyrrolidine derivatives disclosed that a *cis*-methoxy group at C-4 of the pyrrolidine improved the binding 5-fold and 25-fold for the *trans*-isomer. When this strategy was applied to the  $\alpha$ -keto amide isostere, a *cis*-benzyl ether at C-4 was found to enhance binding 3-fold. Of the core structures prepared as 5 inhibitors of the HIV protease, none show significant inhibitory activity against the mechanistically identical FIV protease, and additional complementary groups are needed to improve inhibition.

10 Another aspect of the invention is directed to the use of FIV PR as a model for the development of HIV PR inhibitors and for the study of drug resistance. This disclosure is supported by the data reported herein and by several additional 15 observations. First, both enzymes are mechanistically identical. Second, structure-based alignment of the two enzymes displays their structure similarity (Figures 11 and 12). Third, most potent 20 non-covalent inhibitors of the HIV PR are not good inhibitors of the FIV PR, whereas FIV PR inhibitors are often better HIV PR inhibitors. Therefore, good 25 low molecular weight inhibitors of the FIV PR are disclosed to be better for the HIV PR. Fourth, the HIV PR isolated from the inhibitor-resistant mutants contains mutations that are found in the 30 corresponding positions of the FIV PR. As shown in Figure 12, the six highlights represent the changed amino acids found in the HIV PR isolated from mutants

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resistant to HIV PR inhibitors which are identical to those found in the FIV PR in the same position.

Accordingly, FIV PR is disclosed to be a good model for the development of HIV PR inhibitors with less 5 resistance problem. For example, the HIV PR isolated from a mutant resistant to a synthetic protease inhibitor contains the I50V mutation, and the mutant protease is less inhibited by the same inhibitor by 80-fold.

10 Table I. Inhibition activities against HIV and/or FIV PR. The inhibitory activities of various isosteres against the HIV and/or FIV PR illustrating a dual screening method against these related viral proteases are illustrated in Table I provided below:

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Table I. Inhibition activities against HIV and/or FIV PR.

Compound	HIV PR		FIV PR	
	$IC_{50}$	$K_i$	$IC_{50}$	$K_i$
<b>1</b>	6 $\mu$ M	6 $\mu$ M	-	-
<b>2</b>	700nM	214nM	>70mM	-
<b>2a</b>	1.57 $\mu$ M	220nM		
<b>2b</b>	1.9 $\mu$ M	318nM		
<b>2c</b>	460nM	65nM		
<b>3</b>	3.18 $\mu$ M	405nM	-	-
<b>4</b>	-	154nM	25 $\mu$ M	29 $\mu$ M
<b>5</b>	1.8mM	-	-	-
<b>6</b>	100 $\mu$ M	-	-	-
<b>7</b>	1.6mM	-	-	-
<b>8</b>	60 $\mu$ M	-	-	-
<b>9</b>	17 $\mu$ M	-	-	-
<b>10</b>	2.9 $\mu$ M	-	-	-
<b>11</b>	3.9 $\mu$ M	-	-	-
<b>12</b>	20 $\mu$ M	-	-	-

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Synthetic Methods

1) Biological Assays

5           For determination of IC<sub>50</sub> values for HIV  
protease, a backbone engineered HIV-1 protease,  
prepared by total chemical synthesis (Kent et. al.  
Science 1992, 256, 221) 450 nM final concentration  
was added to a solution (152 µL final volume)  
10          containing inhibitor, 28 µM fluorogenic peptide  
substrate (sequence Abz-Thr-Ile-Nle-Phe-(p-NO<sub>2</sub>)-Gln-  
Arg-NH<sub>2</sub> (Toth et. al., Int. J. Peptide Res. 1990, 36,  
544)) and 1.8 % dimethylsulfoxide in assay buffer:  
15          100mM MES buffer containing 0.5 mg/mL BSA (Bovine  
Serum Album, fatty acid, nuclease and protease free -  
to stabilize enzyme) at pH 5.5. The solution was  
mixed and incubated over 5 minutes during which time  
the rate of substrate cleavage was monitored by  
continuously recording the change in fluorescence of  
20          the assay solution. An excitation filter of 325 nm,  
and an emission filter of 420 nm were used. This  
data was converted into µM substrate cleaved per  
minute, using a predetermined standard calibration  
curve of change in fluorescence against concentration  
25          of substrate cleaved.

Determination of K<sub>i</sub> for HIV protease was  
performed similarly with the following modifications.  
The substrate concentrations used were 57, 43, 28 and  
14 µM. All other concentrations were as above. The  
30          curve fit for the data was determined and the  
subsequent K<sub>i</sub> derived using a computer program based  
on the equation of Morrison et. al. BioChim.  
Biophys. ACTA 1969, 185, 269, for tight binding

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inhibitors.

For determination of  $K_i$  and  $IC_{50}$  for FIV protease, 0.125 µg of the enzyme was added to a solution (100µL final volume) containing inhibitor, 5 560 µM peptide substrate (sequence Gly-Lys-Glu-Glu-Gly-Pro-Pro-Gln-Ala-Tyr~Pro-Ile-Gln-Thr-Val-Asn-Gly) and 2% dimethyl sulfoxide in a 1:3 mixture of assay buffer (as above) and 4M NaCl<sub>aq.</sub> solution. The solution was mixed and incubated for 10 minutes at 37 10 °C and the reaction quenched by addition of 8M guanidine HCl solution containing 0.2 M sodium acetate at pH 4.2 (100 µL). The cleavage products and substrate were separated by reverse phase HPLC. Absorbance was measured at 215 nm, peak areas were 15 determined and percent conversion to product was calculated using relative peak areas. The data were plotted as 1/V (V = rate substrate is cleaved in nmol/min) against inhibitor concentration and the  $-K_i$  determined as the point at which the resulting line intersects with 1/ $V_{max}$  ( $V_{max} = 6.85$  nmol/min).  $IC_{50}$  20 was determined as the inhibitor concentration at 50% inhibition.  $V_{max}$  ( $6.85 \pm 0.7$  nmol min<sup>-1</sup>) and  $K_m$  ( $707 \pm 70$  µM) for FIV protease were determined from a plot of 1/V (V = rate in nmol/min) against 1/[S] ([S] = 25 substrate concentration in nmol). The data used was generated similarly to that for  $K_i$  with the following modifications. The substrate concentrations used were 560, 448, 336, 224, 111 and 56 µM, in the absence of inhibitor.

30 Purification of FIV protease: A 503 base pair Eco R1-Bam H1 fragment containing the coding sequence of FIV protease was cloned from FIV-34TF10 (Talbott et. al. Proc. Natl. Acad. Sci. USA 86 1989, 5743)

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into the pT7-7 vector (Tabor et. al. Proc. Natl. Acad. Sci USA 82 1985, 1074). The 5' end of the insert was modified by the addition of an NdeI adaptor, which provided the proper reading frame with initiation of translation from the methionine encoded in the latter site. Translation resulted in production of an 18.6 kDa precursor, which auto-processed to a 13.2 kDa FIV PR plus N- and C-terminal fragments of 3.6 kDa and 1.8 kDa, respectively. The construct was transformed into *E. coli* strain BL21(DE3), lys S (Studier et. al. Meth. Enzymol. 1990, 185, 60) and overnight cultures were used to inoculate 15 liter fermentations, performed using Circlegrow medium (Bio 101) plus 100 µL ampicillin, 20 µM chloramphenicol, at 37 °C. The cells were allowed to reach mid-log phase, then the temperature was reduced to 24 °C and IPTG (isopropylβ-thiogalactopyranoside) was added to a final concentration of 1 mM. The fermentation was allowed to proceed for 16 hours, at which time the cells were harvested by centrifugation and frozen at -70 °C in 100 g aliquots for future use.

Cells (100 g) were lysed by addition of 600 mL, 50 mM Tris-HCl, pH 8, 5 mM EDTA and 2 mM 2-mercaptopethanol to the frozen pellet. The cells lysed upon thawing and the viscous mixture was homogenized at 4 °C for 2 min in a Waring blender. The sample was centrifuged at 8,000 x g for 20 min and the pellet discarded. The sample was diluted to 1 liter, then subjected to tangential flow against a 300 K cut-off membrane (Filtron) and the PR was washed through the membrane using five liters of the same buffer. The retentate was discarded and the

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flow-through supernatant concentrated by tangential flow against a 10 K cut-off membrane. The retentate was passed over a DE52 anion exchange column (5 x 20 cm) equilibrated in the same buffer. The flow-through from this column was passed over an S-Sepharose Fast Flow matrix (2.5 x 20 cm column, Pharmacia), again equilibrated at pH 8 in the same buffer. The flow-through from S-Sepharose was made 1M with respect to ammonium sulfate and applied to a phenyl sepharose column (Pharmacia, 1.5 x 10 cm), washed with lysis buffer containing 1M ammonium sulfate, then eluted with a 100-0% linear ammonium sulfate gradient. Peak fractions containing PR were pooled, concentrated using Centriprep (Amicon), and dialyzed against 10 mM Tris-HCl, pH 8, 5 mM EDTA, 2 mM 2-mercaptoethanol. The sample was made 10 mM with respect to MOPS, adjusted to pH 5.5 with HCl, then applied to a Resource S column (Pharmacia) equilibrated in 10 mM Tris-MOPS, pH 5.5, 5 mM EDTA and 2 mM 2-mercaptoethanol. PR was eluted using a linear 0-300 mM NaCl gradient in the same buffer. Peak fractions were pooled, concentrated, and stored as aliquots at -20 °C for further studies. The integrity of the isolated FIV PR was confirmed by ion spray mass spectrometry.

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2) Chemical Synthesis

All manipulations were conducted under an inert atmosphere (argon or nitrogen). All solvents were reagent grade. Anhydrous ether, tetrahydrofuran (THF), and toluene were distilled from sodium and/or benzophenone ketyl. Dichloromethane ( $\text{CH}_2\text{Cl}_2$ ) was distilled from calcium hydride ( $\text{CaH}_2$ ). *N,N*-Dimethylformamide (DMF) and acetonitrile were distilled from phosphorous pentoxide and calcium hydride. Methanol was distilled from magnesium and iodine. Organic acids and bases were reagent grade. All other reagents were commercial compounds of the highest purity available. Analytical thin-layer chromatography (TLC) was performed on Merck silica gel (60 F-254) plates (0.25 mm). Visualization was effected using standard procedures unless otherwise stated. Flash column chromatography was carried out on Merck silica gel 60 particle size (0.040-0.063 mm, 230-400 Mesh). Melting points were determined with a Thomas-Hoover capillary melting point apparatus and are uncorrected. Proton and carbon magnetic resonance spectra ( $^1\text{H-NMR}$ ,  $^{13}\text{C-NMR}$ ) were recorded on either a Bruker AM-500, AMX-400 or AC250MHz Fourier transform spectrometer. Coupling constants ( $J$ ) are reported in hertz and chemical shifts are reported in parts per million ( $\delta$ ) relative to tetramethylsilane (TMS, 0 ppm), MeOH (3.30 ppm for  $^1\text{H}$  and 49.0 ppm for  $^{13}\text{C}$ ) or  $\text{CHCl}_3$  (7.24 ppm for  $^1\text{H}$  and 77.0 ppm for  $^{13}\text{C}$ ) as internal reference. Infrared spectra (IR) were recorded on a Perkin-Elmer 1600 series FT-IR spectrophotometer. Absorptions are reported in wavenumbers ( $\text{cm}^{-1}$ ).

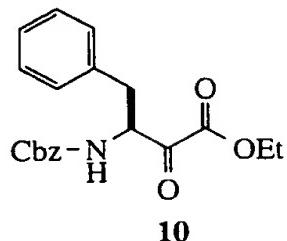
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Peptide fragments described herein were synthesized using traditional peptide coupling methodologies [EDC (1-(3-dimethylaminopropyl)-3-ethylcarbodiimide HCl), HOBr (1-hydroxybenzotriazole) and DIEA (diisopropylethylamine)]. Esters were hydrolyzed either by base (LiOH for methyl esters) or acid (TFA for *t*-butyl esters).

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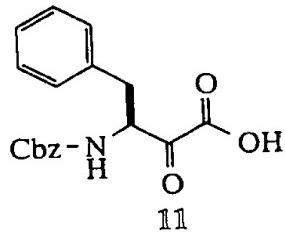
Synthesis of compound 10 as illustrated in figure 6



Compound 10: The  $\alpha$ -keto ester 10 was synthesized  
5 according to the method described by Angelastro et  
al. *J. Org. Chem.* 1989, 54, 3913-3916. It is  
possible to synthesize  $\alpha$ -keto esters via other  
methodologies, Wasserman, et al. *J. Org. Chem.* 1994,  
10 59, 4364-4366(43); Wong et al. *J. Med. Chem.* 1993, 36,  
211-220, but the route employed was found to be most  
concise and high yielding. The methodology, shown in  
figure 1 and described by Angelastro, is as follows  
(i) *t*-BuLi, ethyl vinyl ether, MgBr<sub>2</sub>, THF; (ii) O<sub>3</sub>,  
CH<sub>2</sub>Cl<sub>2</sub>.

15

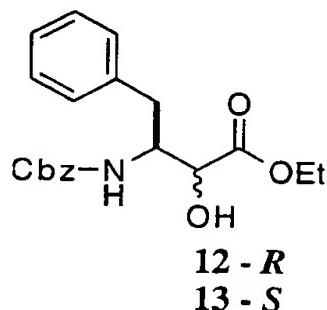
Synthesis of compound 11 as illustrated in figure 6,  
step (iii)



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Compound 11. To a 2:1 solution of compound 10 in methanol/water (.10 Molar) is added a 0.17 Normal solution of LiOH in water and the reaction is allowed to stir at 0 °C for 2 hours. The mixture is then purified by reverse phase chromatography and yielded compound 11 in 98% overall yield.

Synthesis of (2R, 3S) and (2S, 3S) N-(Benzylxycarbonyl)-AHAP-(3-Amino-2-Hydroxy-4-Phenylbutanoic Acid) Ethyl Ester 12 and 13 as shown in figure 7.



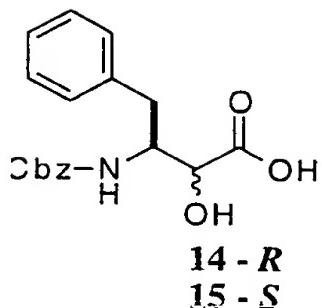
As illustrated in figure 7, step i, the substrate 10 (600 mg, 1.7 mmol) was dissolved in methanol (10 mL) and cooled to 0 °C. Sodium Borohydride (70.3 mg, 1.9 mmol) was then added. After 20 minutes the reaction was quenched by addition of saturated ammonium chloride<sub>(aq.)</sub> (10 mL). The reaction mixture was concentrated *in vacuo* to remove most of the methanol. The aqueous residue was then extracted with ethyl acetate (3 x 20 mL), washed with brine (10 mL), dried ( $MgSO_4$ ) and concentrated *in vacuo* to give the crude product as a mixture of diastereomers. The alcohols

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were separated by flash chromatography eluting with 15% ethyl acetate in hexane to give the alcohols in a ratio of 3:4, 12 & 13 (590 mg, 97%).  $R_f$  = 0.54 and 0.40 respectively (EtOAc/Hexane, 1:2): 12 (2R, 3S - colorless oil);  $^1\text{H}$  NMR (500MHz,  $\text{CDCl}_3$ )  $\delta$  7.34-7.18 (10H, m), 5.17 (1H, d,  $J$  9.5), 5.04 (2H, s), 4.43-4.38 (1H, m), 4.33 (1H, dd,  $J$  4.5, 2.0), 4.15-4.08 (1H, m), 3.98-3.92 (1H, m), 3.28 (1H, d,  $J$  5.0); IR (NaCl)  $\nu_{\text{max}}$  3368, 3030, 2981, 1731, 1520, 1455, 1246, 1104, 1055, 748, 699  $\text{cm}^{-1}$ ; FABHRMS (NBA)  $m/e$  358.1659 ( $[\text{M}+\text{H}]^+$ ,  $\text{C}_{20}\text{H}_{23}\text{NO}_5$  requires 358.1654); (Found: C, 67.30; H, 6.50; N, 3.99.  $\text{C}_{20}\text{H}_{23}\text{NO}_5$  requires C, 67.21; H, 6.49; N, 3.92%). 13 (2S, 3S - crystalline);  $^1\text{H}$  NMR (500MHz,  $\text{CDCl}_3$ )  $\delta$  7.34-7.18 (10H, m), 5.17 (1H, d,  $J$  9.5), 5.04 (2H, s), 4.43-4.38 (1H, m), 4.33 (1H, dd,  $J$  4.5, 2.0), 4.15-4.08 (1H, m), 3.98-3.92 (1H, m), 3.28 (1H, d,  $J$  5.0); IR (NaCl)  $\nu_{\text{max}}$  3368, 3030, 2980, 1731, 1520, 1455, 1246, 1104, 1055, 748, 699  $\text{cm}^{-1}$ ; FABHRMS (NBA)  $m/e$  358.1661 ( $(\text{M}^+ + \text{H})$ ,  $\text{C}_{20}\text{H}_{23}\text{NO}_5$  requires 358.1654); (Found: C, 67.22; H, 6.57; N, 3.90.  $\text{C}_{20}\text{H}_{23}\text{NO}_5$  requires C, 67.21; H, 6.49; N, 3.92%). m.p. 88-89°C.

Synthesis of (2R, 3S) and (2S, 3S) N-  
25 (Benzylloxycarbonyl)-3-Amino-2-Hydroxy-4-  
Phenylbutanoic Acid 14 & 15 respectively as  
illustrated in figure 7

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As illustrated in figure 7, step ii, the substrate (12 or 13) (250 mg, 0.70 mmol) was dissolved in 0.25 N LiOH in methanol/water, 2:1 (5 mL), and stirred at ambient temperature for 30 minutes. The pH of the reaction was adjusted to pH 7.0 with 1N HCl (aq.) and the methanol removed *in vacuo*. The aqueous residue was then acidified to pH 2.0 with 1N HCl (aq.) and extracted with ethyl acetate (3 x 30 mL). The combined organic extracts were washed with water (10 mL), brine (10 mL) and dried ( $\text{MgSO}_4$ ) before concentration *in vacuo* to give the desired acid (14 or 15) as a white solid (212 mg, 92%). The acids were purified by recrystallization from hot ethanol.

**14 (2R, 3S);**  $^1\text{H}$  NMR (500MHz,  $\text{CD}_3\text{OD}$ )  $\delta$  7.31-7.18 (10H, m), 6.87 (1H, d,  $J$  9.5), 5.00 (1H, d,  $J$  10.0), 4.96 (1H, d,  $J$  10.0), 4.31-4.23 (1H, m), 4.07 (1H, d,  $J$  2.5), 2.93 (1H, dd,  $J$  13.5, 7.5), 2.83 (1H, dd,  $J$  13.5, 8.0);  $^{13}\text{C}$  NMR (125MHz,  $\text{CD}_3\text{OD}$ )  $\delta$  176.6 (C=O), 158.5 (C=O), 139.8 (C), 138.5 (C), 130.7 (2 x CH), 129.8 (2 x CH), 129.7 (2 x CH), 129.7 (CH), 129.1

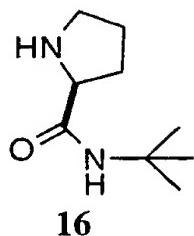
-46-

(CH), 128.8 (CH), 127.8 (CH), 67.6 (CH), 57.1 (CH<sub>2</sub>),  
57.0 (CH<sub>2</sub>), 39.3 (CH); FABHRMS (NBA) *m/e* 330.1353  
([M+H]<sup>+</sup>, C<sub>18</sub>H<sub>19</sub>NO<sub>5</sub> requires 330.1341); m.p. 209-210  
(decomp.). 15 (2S, 3S); <sup>1</sup>H NMR (500MHz, CD<sub>3</sub>OD) δ  
5 7.28-7.18 (10H, m), 7.09 (1H, d, *J* 12.5), 4.97 (1H,  
d, *J* 12.5), 4.92 (1H, d, *J* 12.5), 4.26 (1H, d, *J*  
4.0), 4.25-4.20 (1H, m), 2.81 (1H, dd, *J* 14.0, 4.0),  
2.76 (1H, dd, *J* 14.0, 4.0); <sup>13</sup>C NMR (125MHz, CD<sub>3</sub>OD)  
δ 175.9 (C=O), 158.5 (C=O), 140.0 (C), 138.6 (C),  
10 130.6 (3 x CH), 129.6 (CH), 129.5 (3 x CH), 129.0  
(CH), 128.8 (CH), 127.6 (CH), 74.3 (CH), 67.4 (CH<sub>2</sub>),  
57.1 (CH), 36.5 (CH<sub>2</sub>); FABHRMS (NBA/NaI) *m/e*  
352.1174 ([M+Na]<sup>+</sup>, C<sub>18</sub>H<sub>19</sub>NO<sub>5</sub> requires 352.1161);  
(Found: C, 65.34; H, 5.75; N, 4.33. C<sub>18</sub>H<sub>19</sub>NO<sub>5</sub>  
15 requires C, 65.64; H, 5.82; N, 4.25%); m.p. 173-174°C  
(decomp.).

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Synthesis of L-Prolyl-tert-butyl amide 16 (scheme 7)



The substrate *N*-tert-Butoxycarbonyl-L-proline  
5 commercially available from Sigma, (3.0 g, 13.9 mmol), was dissolved in dry  $\text{CH}_2\text{Cl}_2$  (20 mL). HOBT, 1-hydroxybenzotriazole hydrate (2.07 g, 15.3 mmol), EDC, 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide, (2.93 g, 15.3 mmol), and tert-butylamine (1.6 mL, 10 15.3 mmol), were added and the mixture stirred for 18 hours at ambient temperature. The reaction was diluted with ethyl acetate (100 mL), and washed with water (2 x 20 mL), 1 N HCl (aq.) (10 mL), saturated sodium bicarbonate solution (aq.) (10 mL), water (10 mL), brine (10 mL) and dried ( $\text{MgSO}_4$ ) before concentration *in vacuo* to give the crude product. Purification by flash chromatography, eluting with 33% EtOAc in Hexane gave *N*-tert-butoxycarbonyl-L-prolyl-tert-butyl amide as a colorless oil (1.53 mg, 20 40%).  $R_f$  = 0.46 (EtOAc/Hexane, 1:1).  $^1\text{H}$  NMR signals broadened due to rotamers:  $^1\text{H}$  NMR (500MHz,  $\text{CDCl}_3$ )  $\delta$  7.31-7.25 (5H, m), 6.35 (1H, br s), 4.60-4.15 (3H, m), 3.55-3.22 (2H, m), 2.41-1.70 (4H, m), 1.60-1.18 (9H, br s); IR (NaCl)  $\nu_{\text{max}}$  3298, 3086, 2976, 1698, 25 1660, 1531, 1398, 1162  $\text{cm}^{-1}$ ; FABHRMS (NBA/NaI)  $m/e$

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293.1832 ([M+Na]<sup>+</sup>, C<sub>14</sub>H<sub>26</sub>N<sub>2</sub>O<sub>3</sub> requires 293.1841). The N-tert-Butoxycarbonyl-L-prolyl-tert-butyl amide was carried on as follows:

N-tert-Butoxycarbonyl-L-prolyl-tert-butyl amide

5 (600 mg, 2.22 mmol) was dissolved in CH<sub>2</sub>Cl<sub>2</sub> (10 mL) and cooled to 0 °C. TFA, trifluoracetic acid, (10 mL) was then added to the solution. After 1 hour at 0 °C the reaction was concentrated *in vacuo* (any remaining TFA was removed under high vacuum) to give  
10 the trifluoroacetic acid salt of the desired amine 16 as a colorless oil (800 mg, 95%). The amine was used without further purification in subsequent coupling steps. <sup>1</sup>H NMR (500MHz, CDCl<sub>3</sub>) δ 7.30 (1H, br s), 6.90 (1H, br s), 4.52 (1H, br s), 3.35 (2H, br s),  
15 2.49-2.34 (1H, m), 2.08-1.97 (3H, m), 1.34 (9H, s); <sup>13</sup>C NMR (125MHz, CDCl<sub>3</sub>) δ 167.4 (C=O), 59.6 (CH), 52.3 (C), 46.6 (CH<sub>2</sub>), 30.4 (CH<sub>2</sub>), 28.2 (3 × CH<sub>3</sub>), 24.6 (CH<sub>2</sub>); FABHRMS (NBA) m/e 171.1500 ([M+H]<sup>+</sup>, C<sub>9</sub>H<sub>18</sub>N<sub>2</sub>O requires 171.1497).

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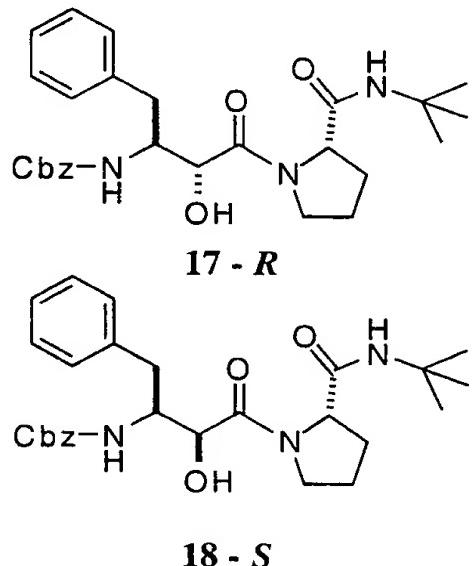
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General peptide coupling procedure as illustrated in figure 7:

Synthesis of (2S, 3R) and (2S, 3S) 3-(N-Benzylloxycarbonyl)amino-2-hydroxy-4-phenylbutyryl-L-prolyl-tert-butyl amide 17 and 18.

5



As illustrated in figure 7, step iii, the substrate  
10 14 or 15 (70 mg, 0.213 mmol), was dissolved in dry  
DMF (3 mL). HOBT, 1-hydroxybenzotriazole hydrate  
(31 mg, 0.22 mmol), EDC, 1-(3-dimethylaminopropyl)-3-  
ethylcarbodiimide, (43 mg, 0.224 mmol), DIEA,  
diisopropylethylamine, (122 µl, 0.703 mmol) were  
15 added and the mixture stirred for 30 minutes at room

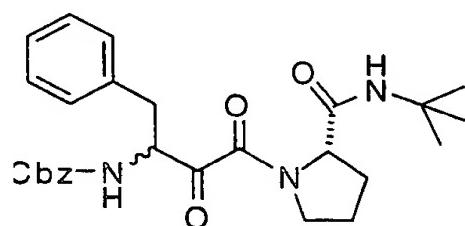
temperature. The secondary amine **16** as its TFA salt (73 mg, 0.255 mmol) was added and the reaction stirred for 18 hours. The reaction mixture was diluted with ethyl acetate (20 mL) and added to  
5 saturated ammonium chloride (30 mL). The aqueous phase was extracted with ethyl acetate (3 x 10 mL). The combined organic phases were then washed with water (2 x 5 mL), 1 N HCl (aq.) (5 mL), saturated sodium bicarbonate solution (aq.) (50 mL), water (5  
10 mL), brine (5 mL) and dried ( $\text{MgSO}_4$ ) before concentration *in vacuo* to give the crude product. Flash chromatography eluting with ethyl acetate/hexane, 1:1 to give the desired coupled product **17** or **18** as a colorless oil (74 mg, 72%).  $R_f$  = 0.33 and 0.28 respectively (EtOAc:Hexane, 1:1).  
15 **17** (*2R, 3S*);  $^1\text{H}$  NMR (500MHz,  $\text{CDCl}_3$ )  $\delta$  7.37-7.23 (10H, m), 6.44 (1H, s), 5.16 (1H, d, *J* 9.5), 5.03 (2H, s), 4.24-4.18 (1H, m), 4.11 (1H, d, *J* 5.5), 3.97-3.90 (2H, m), 3.28-3.23 (1H, m), 3.12-3.06 (1H, m), 2.99-  
20 2.90 (2H, m), 2.18-2.12 (1H, m), 2.01-1.96 (1H, m), 1.89-1.83 (1H, m), 1.83-1.76 (1H, m), 1.27 (9H, s);  $^{13}\text{C}$  NMR (100MHz,  $\text{CDCl}_3$ )  $\delta$  171.4 (C=O), 169.9 (C=O), 156.0 (C=O), 137.4 (C), 136.7 (C), 129.2 (2 x CH), 128.7 (2 x CH), 128.4 (2 x CH), 128.0 (CH), 127.9 (2  
25 x CH), 126.9 (CH), 68.6 (CH), 66.7 ( $\text{CH}_2$ ), 61.7 (CH), 52.8 (CH), 51.1 (C), 46.1 ( $\text{CH}_2$ ), 38.4 ( $\text{CH}_2$ ), 28.6 (3 x CH<sub>3</sub>), 27.4 (CH<sub>2</sub>), 24.7 (CH<sub>2</sub>); IR (NaCl)  $\nu_{\text{max}}$  3318, 2966, 1714, 1667, 1537, 1454, 1366, 1041  $\text{cm}^{-1}$ ; FABHRMS (NBA) *m/e* 482.2677 ([M+H]<sup>+</sup>,  $\text{C}_{27}\text{H}_{35}\text{N}_3\text{O}_5$  requires 482.2655); (Found: C, 67.22; H, 7.32; N, 8.80.  
30  $\text{C}_{27}\text{H}_{35}\text{N}_3\text{O}_5$  requires C, 67.34; H, 7.33; N, 8.73%). **18** (*2S, 3S*); (major rotamer only)  $^1\text{H}$  NMR (400MHz,  $\text{CDCl}_3$ )

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<sup>5</sup> δ 7.33-7.17 (10H, m), 6.45 (1H, s), 5.21 (1H, d, *J* 8.8), 4.99 (2H, s), 4.60 (1H, dd, *J* 6.8, 2.1), 4.52-4.47 (1H, m), 4.21-4.13 (1H, m), 3.81-3.66 (3H, m), 2.75-2.60 (2H, m), 2.41-2.30 (1H, m), 2.25-2.09 (1H, m), 2.05-1.90 (2H, m), 1.30 (9H, s); <sup>13</sup>C NMR (100MHz, CDCl<sub>3</sub>) δ 171.3 (C=O), 169.6 (C=O), 156.0 (C=O), 137.3 (2 x C), 129.1 (2 x CH), 128.5 (2 x CH), 128.4 (2 x CH), 128.0 (CH), 127.8 (2 x CH), 126.5 (CH), 71.3 (CH), 66.6 (CH<sub>2</sub>), 61.1 (CH), 54.3 (CH), 51.3 (C), 47.5 (CH<sub>2</sub>), 33.8 (CH<sub>2</sub>), 28.6 (3 x CH<sub>3</sub>), 26.9 (CH<sub>2</sub>), 25.4 (CH<sub>2</sub>); IR (NaCl)  $\nu_{\text{max}}$  3318, 2966, 1714, 1667, 1537, 1454, 1366, 1041 cm<sup>-1</sup>; FABHRMS (NBA/CsI) m/e 614.1645 ([M+Cs]<sup>+</sup>, C<sub>27</sub>H<sub>35</sub>N<sub>3</sub>O<sub>5</sub> requires 614.1631); (Found: C, 67.20; H, 7.66; N, 8.54. C<sub>27</sub>H<sub>35</sub>N<sub>3</sub>O<sub>5</sub> requires C, 67.34; H, 7.33; N, 8.73%).

General Dess-Martin oxidation procedure as illustrated in figure 7:

Synthesis of (3S) and (3R) 3-(N-Benzylloxycarbonyl)amino-2-keto-4-phenylbutyryl-L-prolyl-tert-butyl amide 2.



2

3:1 mixture

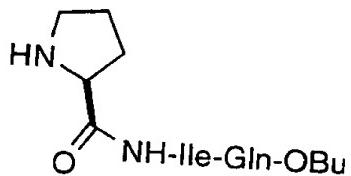
As illustrated in figure 7, step iv, the substrate 17 (21 mg, 0.044 mmol) was dissolved in dry CH<sub>2</sub>Cl<sub>2</sub> (2 mL), and Dess-Martin periodinane (26 mg, 0.088 mmol) added. The reaction mixture was stirred at ambient temperature for 24 hours, then diluted with ethyl acetate (10 mL) and quenched by addition of saturated sodium bicarbonate (aq.) (5 mL) and sodium thiosulfate. The aqueous phase was extracted with ethyl acetate (3 x 20 mL). The combined organic extracts washed with water (10 mL), brine (10 mL), dried (MgSO<sub>4</sub>) and concentrated *in vacuo* to give the crude product. Flash chromatography eluting with 30% ethyl acetate in hexane gave the desired product 2 as a 3:1 mixture of diastereomers (colorless oil) (20 mg, 95%). R<sub>f</sub> = 0.47 (EtOAc/Hexane, 1:2). Spectral data on mixture: <sup>1</sup>H NMR (400MHz, DMSO) δ 7.86 (1H, d, J 7.8), 7.71 (1H, d, J 8.3), 7.64 (1H, s), 7.53 (1H, s), 7.37-7.10 (20 H, m), 5.10 (1H, ddd, J 11.0, 8.3, 2.4), 5.01 (1H, d, J 12.6), 4.95 (1H, d, J 12.6), 4.95 (1H, d, J 16.3), 4.88 (1H, d, J 16.3), 4.79-4.73 (1H, m), 4.66 (1H, dd, J 7.8, 4.2), 4.26 (1H, dd, J 7.8, 4.5), 3.60-3.37 (3H, m), 3.33-3.24 (1H, m), 3.18 (1H, dd, J 14.7, 2.4), 3.13 (1H, dd, J 10.2, 3.9), 2.79 (1H, dd, J 13.7, 10.2), 2.46 (1H, dd, J 14.7, 11.0), 2.23-2.17 (1H, m), 2.04-1.97 (1H, m), 1.90-1.60 (6H, m), 1.24 (9H, s), 1.22 (9H, s); <sup>13</sup>C NMR (100MHz, CDCl<sub>3</sub>) δ 198.91 (C=O), 196.7 (C=O), 170.7 (C=O), 169.9 (C=O), 162.6 (C=O), 162.2 (C=O), 156.1 (C=O), 155.9 (C=O), 138.5 (C), 137.6 (C), 136.9 (C), 136.9 (C), 129.0 (CH x 2), 128.8 (CH x 2), 128.4 (CH x 8), 127.8 (CH x 2), 127.6 (CH x 2), 127.6 (CH x 2),

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126.5 (CH), 126.4 (CH), 65.6 (CH<sub>2</sub>), 65.3 (CH<sub>2</sub>), 60.3  
 (CH), 59.7 (CH), 59.2 (CH), 58.2 (CH), 50.3 (C), 50.1  
 (C), 47.6 (CH<sub>2</sub>), 47.4 (CH<sub>2</sub>), 34.8 (CH<sub>2</sub>), 34.1 (CH<sub>2</sub>),  
 32.5 (CH<sub>2</sub>), 29.1 (CH<sub>2</sub>), 28.5 (CH<sub>3</sub> × 3), 28.4 (CH<sub>3</sub> ×  
 5 3), 24.5 (CH<sub>2</sub>), 21.7 (CH<sub>2</sub>); IR (NaCl)  $\nu_{max}$  3325, 2966,  
 1715, 1670, 1634, 1531, 1454, 1258, 1051, 738, 699;  
 FABHRMS (NBA/NaI) *m/e* 502.2295 ([M+Na]<sup>+</sup>, C<sub>27</sub>H<sub>33</sub>N<sub>3</sub>O<sub>5</sub>  
 requires 502.2318); (Found: C, 67.62; H, 7.05; N,  
 10 8.96. C<sub>27</sub>H<sub>33</sub>N<sub>3</sub>O<sub>5</sub> requires C, 67.62; H, 6.94; N,  
 8.76%).

**Synthesis of L-Prolyl-L-isoleucyl-L-glutamine-tert-butyl amide 19 as illustrated in figure 8**

15



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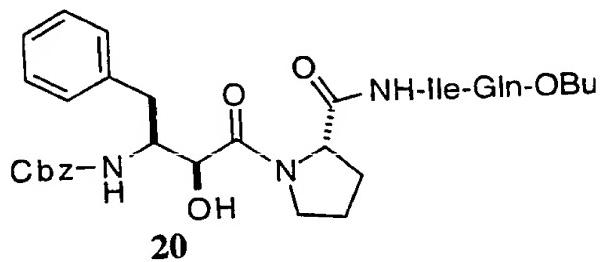
25

As illustrated in figure 8, the substrate *N*-tert-Butoxycarbonyl-L-proline commercially available from Sigma, (3.0 g, 13.9 mmol), was dissolved in dry CH<sub>2</sub>Cl<sub>2</sub> (20 mL). HOBT, 1-hydroxybenzotriazole hydrate (2.07 g, 15.3 mmol), EDC, 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide, (2.93 g, 15.3 mmol), and NH-Ile-Gln-OBu (1.6 mL, 15.3 mmol; peptide fragments were synthesized using traditional peptide coupling methodologies: EDC, HOBT, DIEA, Ile, Gln, and

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protected as a tertButyl-ester), were added and the mixture stirred for 18 hours at ambient temperature. The reaction was diluted with ethyl acetate (100 mL), and washed with water (2 x 20 mL), 1 N HCl (aq.) (10 mL), saturated sodium bicarbonate solution (aq.) (10 mL), water (10 mL), brine (10 mL) and dried ( $MgSO_4$ ) before concentration in vacuo to give the crude product. Purification by flash chromatography, eluting with 33% EtOAc in Hexane gave NH-Ile-Gln-OBu-L-prolyl-tert-butyl amide **19** as a colorless oil (1.53 mg, 40%).  $R_f$  = 0.46 (EtOAc/Hexane, 1:1).  $^1H$  NMR signals broadened due to rotamers: Spectral data:  $^1H$  NMR (400MHz,  $CD_3OD$ )  $\delta$  4.35-4.30 (1H, m), 4.31 (1H, dd,  $J$  9.3, 5.0), 4.21 (1H, d,  $J$  7.8), 3.41-3.26 (2H, m), 2.48-2.36 (1H, m), 2.36-2.22 (2H, m), 2.20-1.79 (6H, m), 1.67-1.54 (1H, m), 1.46 (9H, s), 1.32-1.17 (1H, m), 0.99 (3H, d,  $J$  6.8), 0.93 (3H, t,  $J$  7.4);  $C^{13}$  NMR (100MHz,  $CD_3OD$ )  $\delta$  173.3 (C=O), 172.0 (C=O), 170.1 (C=O), 167.7 (C=O), 83.0 (C), 60.7 (CH), 59.9 (CH), 54.0 (CH), 47.4 (CH<sub>2</sub>), 37.9 (CH), 32.5 (CH<sub>2</sub>), 31.2 (CH<sub>2</sub>), 28.4 (CH<sub>2</sub>), 28.2 (3 x CH<sub>3</sub>), 26.0 (CH<sub>2</sub>), 25.0 (CH<sub>2</sub>), 15.9 (CH<sub>3</sub>), 11.4 (CH<sub>3</sub>); FABHRMS (NBA) *m/e* 435.2575 ([M+Na]<sup>+</sup>,  $C_{20}H_{36}N_4O_5$  requires 435.2583).

Synthesis of (2S, 3S) 3-(N-Benzylloxycarbonyl)amino-2-hydroxy-4-phenylbutyryl-L-prolyl-L-isoleucyl-L-glutamine-tert-butyl amide 20 as illustrated in figure 8



5

As illustrated in figure 8, step i, the coupling of the acid 15 to the amide 19 was carried out using the general peptide coupling procedure. A representative synthesis is as follows: the substrate 15(70 mg, 0.213 mmol), was dissolved in dry DMF (3 mL). HOBT, 1-hydroxybenzotriazole hydrate (31 mg, 0.22 mmol), EDC, 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide, (43 mg, 0.224 mmol), DIEA, diisopropyl-lethylamine, (122  $\mu$ l, 0.703 mmol) were added and the mixture stirred for 30 minutes at room temperature. The secondary amine 19 as its TFA salt (73 mg, 0.255 mmol) was added and the reaction stirred for 18 hours. The reaction mixture was diluted with ethyl acetate (20 mL) and added to saturated ammonium chloride (30 mL). The aqueous phase was extracted with ethyl acetate (3 x 10 mL). The combined organic phases were then washed with water (2 x 5 mL), 1 N HCl (aq.) (5 mL), saturated sodium bicarbonate solution (aq.) (50 mL), water (5 mL), brine (5 mL) and

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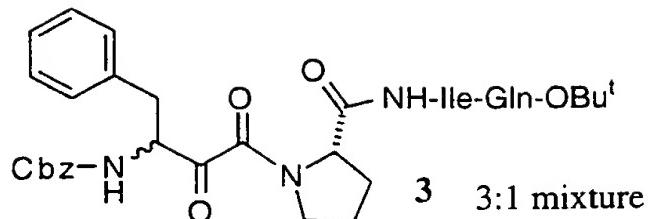
-56-

dried ( $MgSO_4$ ) before concentration *in vacuo* to give the crude product. Flash chromatography eluting with ethyl acetate/hexane, 1:1 to give the desired coupled product 20 as a colorless oil (74 mg, 72%).  $R_f$  = 5 0.33 and 0.28 respectively (EtOAc:Hexane, 1:1) Flash chromatography eluting with 5% methanol in dichloromethane gave the desired product 20 as a colorless oil.  $^1H$  NMR (400MHz,  $CDCl_3$ ) (major rotamer only)  $\delta$  7.42-7.12 (11H, m), 6.95 (1H, d,  $J$  8.6), 6.79 10 (1H, s), 6.07 (1H, s), 5.95 (1H, d,  $J$  8.3), 5.03 (1H, d,  $J$  12.4), 4.96 (1H, d,  $J$  12.4), 4.65 (1H, d,  $J$  4.5), 4.51 (1H, dd,  $J$  8.0, 5.2), 4.49-4.35 (2H, m), 4.32 (1H, d,  $J$  7.8), 3.99-3.94 (1H, m), 3.70-3.50 15 (2H, m), 2.91-2.83 (2H, m), 2.28-2.21 (1H, m), 2.21-2.10 (3H, m), 2.02-1.75 (5H, m), 1.43 (9H, s), 1.14-1.06 (1H, m), 0.86 (3H, d,  $J$  6.4), 0.78 (3H, t,  $J$  7.6);  $C^{13}$  NMR (100MHz,  $CDCl_3$ )  $\delta$  175.5 (C=O), 172.2 (C=O), 171.5 (2 x C=O), 170.4 (C=O), 156.3 (C=O), 137.9 (C), 136.3 (C), 129.1 (2 x CH), 128.4 (4 x CH), 20 128.0 (CH), 127.6 (2 x CH), 126.4 (CH), 82.4 (C), 71.4 (CH), 66.5 (CH<sub>2</sub>), 61.2 (CH), 57.8 (CH), 55.5 (CH), 52.3 (CH), 47.7 (2 x CH<sub>2</sub>), 37.0 (CH), 33.8 (CH<sub>2</sub>), 31.48 (CH<sub>2</sub>), 28.76 (CH<sub>2</sub>), 27.9 (3 x CH<sub>3</sub>), 25.3 (CH<sub>2</sub>), 24.8 (CH<sub>2</sub>), 15.3 (CH<sub>3</sub>), 11.0 (CH<sub>3</sub>); FABHRMS 25 (NBA/CsI) *m/e* 856.288 ([M+Cs]<sup>+</sup>,  $C_{38}H_{53}N_5O_9$  requires 856.2898).

(3S) and (3R) 3-(*N*-Benzylloxycarbonyl)amino-2-keto-4-phenylbutyryl-L-prolyl-L-isoleucyl-L-glutamine-tert-butyl amide 3 as illustrated in figure 8

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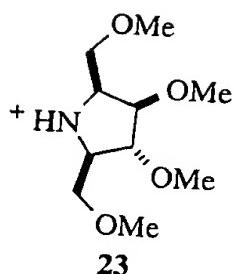


As illustrated in figure 8, oxidation of 20 was carried out using the general Dess-Martin oxidation procedure outlined above. Purification by flash chromatography eluting with 5% methanol in dichloromethane gave the desired  $\alpha$ -keto amide 3(S) (2:1 mixture of isomers) as a colorless oil (37 mg, quantitative). A representative synthesis is as follows: the substrate 20 (21 mg, 0.044 mmol) was dissolved in dry CH<sub>2</sub>Cl<sub>2</sub> (2 mL), and Dess-Martin periodinane (26 mg, 0.088 mmol) added. The reaction mixture was stirred at ambient temperature for 24 hours, then diluted with ethyl acetate (10 mL) and quenched by addition of saturated sodium bicarbonate (aq.) (5 mL) and sodium thiosulfate. The aqueous phase was extracted with ethyl acetate (3 x 20 mL). The combined organic extracts washed with water (10 mL), brine (10 mL), dried (MgSO<sub>4</sub>) and concentrated in vacuo to give the crude product. Flash chromatography eluting with 30% ethyl acetate in hexane gave the desired product 3 as a 3:1 mixture of diastereomers (colorless oil) (20 mg, 95%). (S) isomer: R<sub>f</sub> = 0.24 (EtOAc). <sup>1</sup>H NMR (400MHz, CDCl<sub>3</sub>)  $\delta$  7.38-7.16 (11H, m), 6.98 (1H, d, J 8.5), 6.80 (1H, s), 6.64 (1H, s), 5.64 (1H, d, J 8.3), 5.09 (1H, d, J

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12.2), 5.02 (1H, d, *J* 12.2), 4.46 (1H, dd, *J* 8.2,  
3.4), 4.21 (1H, t, *J* 8.1), 3.67-3.60 (1H, m), 3.59-  
3.45 (1H, m), 3.70-3.50 (2H, m), 3.25 (1H, dd, *J*  
14.1, 5.5), 3.09 (1H, dd, *J* 14.1, 8.5), 2.29-2.12  
5 (4H, m), 2.12-1.78 (6H, m), 1.46 (9H, s), 1.20-1.05  
(1H, m), 0.93-0.83 (6H, m, 2 x CH<sub>3</sub>); C<sup>13</sup> NMR (100MHz,  
CDCl<sub>3</sub>) δ 197.1 (C=O), 175.1 (C=O), 171.1 (C=O), 170.5  
(2 x C=O), 162.9 (C=O), 156.3 (C=O), 135.7 (2 x C),  
129.1 (2 x CH), 128.7 (2 x CH), 128.5 (2 x CH), 128.5  
10 (CH), 127.5 (2 x CH), 126.9 (CH), 82.4 (C), 77.2  
(CH), 67.3 (CH<sub>2</sub>), 61.0 (CH), 58.0 (CH), 52.3 (CH),  
48.0 (2 x CH<sub>2</sub>), 37.0 (CH), 31.5 (CH<sub>2</sub>), 29.7 (CH<sub>2</sub>),  
28.2 (CH<sub>2</sub>), 27.9 (3 x CH<sub>3</sub>), 25.0 (CH<sub>2</sub>), 24.8 (CH<sub>2</sub>),  
15.5 (CH<sub>3</sub>), 10.8 (CH<sub>3</sub>). (3R) isomer: <sup>1</sup>H NMR (400MHz,  
15 CDCl<sub>3</sub>) δ 7.38-7.16 (11H, m), 6.84 (1H, d, *J* 8.0), 6.21  
(1H, s), 5.54 (1H, s), 5.51 (1H, d, *J* 8.3), 5.11-4.98  
(1H, m), 5.09 (1H, d, *J* 12.5), 4.80 (1H, d, *J* 12.5),  
4.75-4.61 (1H, m), 4.59 (1H, d, *J* 5.8), 4.50-4.29  
(2H, m), 3.59-3.45 (1H, m), 3.29 (1H, dd, *J* 14.,  
20 3.9), 2.85 (1H, dd, *J* 14.0, 10.0), 2.29-2.12 (4H, m),  
2.12-1.78 (6H, m), 1.46 (9H, s), 1.20-1.05 (1H, m),  
0.93-0.83 (6H, m, 2 x CH<sub>3</sub>). IR (NaCl) ν<sub>max</sub> 3290,  
2925, 1728, 1648, 1537, 1452, 1367, 1247, 1157;  
FABHRMS (NBA/CsI) m/e 854.2775 ([M+Cs]<sup>+</sup>, C<sub>38</sub>H<sub>51</sub>N<sub>5</sub>O<sub>9</sub>  
25 requires 854.2741).

2 (R), 5 (R)-Bis(methoxymethyl)-3 (R),  
4 (S) (dimethoxy) Npyrrolidine 23 as illustrated in  
figure 12



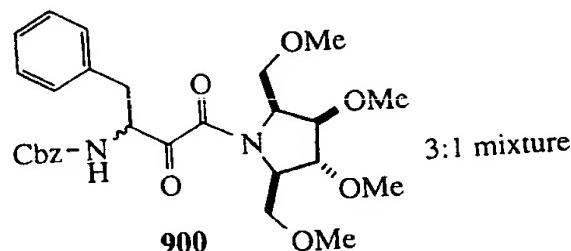
As illustrated in figures 11 and 12, a solution of 2(R), 5(R)-bis(hydroxymethyl)-3(R), 4(S)-dihydroxypyrrolidine (806 mg, 4.95 mmol; Wong et. al J. Org. Chem. 1991, 56, 6280) in H<sub>2</sub>O (25 mL) was cooled to 0 °C in an ice bath and the pH was adjusted to 9-10 with Na<sub>2</sub>CO<sub>3</sub> solution (0.3M). Benzylloxycarbonyl chloride (1.4 mL, 9.9 mmol, 2 eq.) was added dropwise and the solution was stirred 1 hour at 0 °C, and then 1 hour at ambient temperature. Solvent was removed *in vacuo*, and the residue was taken up in EtOAc, filtered, and concentrated *in vacuo*. Flash chromatography eluting initially with 50% ethyl acetate in hexane then 100% ethyl acetate gave 2(R), 5(R)-bis(hydroxymethyl)-3(R), 4(S)-dihydroxy-N-(Benzylloxycarbonyl)-pyrrolidine product as a pale yellow oil. (1.1g, 81%). R<sub>f</sub> = 0.27 (EtOAc)  
<sup>1</sup>H NMR (400MHz, CD<sub>3</sub>OD) δ 7.37-7.33 (5H, m), 5.13 (2H, s), 4.20-4.19 (1H, m), 4.13-4.10 (1H, m), 4.00 (1H, br s), 3.95-3.55 (5H, m); <sup>13</sup>C NMR (100MHz, CD<sub>3</sub>OD) (two rotamers) δ 137.8, 129.6, 129.2, 129.0, 77.8, 77.1, 68.4, 67.4, 66.7, 63.2, 62.2, 61.7, 61.6, 61.1; FABHRMS (NBA) m/e 320.1121 ([M+Na]<sup>+</sup> C<sub>14</sub>H<sub>19</sub>NO<sub>6</sub> requires 320.1110).

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To 2(*R*), 5(*R*)-bis(hydroxymethyl)-3(*R*), 4(*S*)-dihydroxy-*N*-(Benzylloxycarbonyl)-pyrrolidine as synthesized above (35 mg, 0.117 mmol) in dry THF (1 mL) was added CH<sub>3</sub>I (116  $\mu$ L, 1.86 mmol, 16 eq.) followed by NaH (60% dispersion in mineral oil) (28.1 mg, 6 eq.). The reaction mixture was stirred at ambient temperature for 20 h. and concentrated *in vacuo*. Flash chromatography eluting with 12% to 20% ethyl acetate in hexane gave 2(*R*), 5(*R*)-bis(methoxymethyl)-3(*R*), 4(*S*)-dimethoxy-*N*-(Benzylloxycarbonyl)-pyrrolidine as a colorless oil. (40mg, 97%). R<sub>f</sub> = 0.6 (50% EtOAc in Hexane) <sup>1</sup>H NMR (400MHz, CD<sub>3</sub>OD)  $\delta$  7.29-7.23 (5H, m), 5.04 (2H, br s), 4.10 (1H, br s), 3.74 (3H, br, s), 3.44-3.42 (4H, m), 3.34 (3H, br s), 3.31 (3H, br s), 3.23 (6H, br s); FABHRMS (NBA) m/e 376.1722 ([M+Na]<sup>+</sup> C<sub>18</sub>H<sub>27</sub>NO<sub>6</sub> requires 376.1736).

To 2(*R*), 5(*R*)-bis(methoxymethyl)-3(*R*), 4(*S*)-dimethoxy-*N*-(Benzylloxycarbonyl)-pyrrolidine as synthesized above, (40 mg, 0.181 mmol), in methanol (2 mL) was added Pd/C (10 mg). The mixture was stirred under a balloon of H<sub>2</sub> for 3 h. Filtration through celite followed by concentration *in vacuo* yielded the desired product **23** as a pale yellow oil (25 mg, quant.). <sup>1</sup>H NMR (250MHz, CDCl<sub>3</sub>)  $\delta$  5.19 (1H, br s) 3.8-3.55 (8H, m), 3.54-3.35 (12H, m); <sup>13</sup>C NMR (62MHz, CDCl<sub>3</sub>) 84.7, 83.7, 71.9, 69.1, 62.4, 59.9, 59.1, 59.0, 57.6, 57.5; FABHRMS (NBA) m/e 220.1543 ([M+H]<sup>+</sup> C<sub>10</sub>H<sub>21</sub>NO<sub>4</sub> requires 220.1549).

Synthesis of (3S) and (3R) 3-(N-Benzylloxycarbonyl)amino-2-keto-4-phenylbutyryl-[2' (R), 5' (R)-bis(methoxymethyl)-3' (R), 4' (S)-dimethoxypyrrolidine] 900 as illustrated in figure 12



As illustrated in figure 12, step i-ii, the substrate 15 (70 mg, 0.213 mmol), was dissolved in dry DMF (3 mL). HOBT, 1-hydroxybenzotriazole hydrate (31 mg, 0.22 mmol), EDC, 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide, (43 mg, 0.224 mmol), DIEA, diisopropylethylamine, (122  $\mu$ L, 0.703 mmol) were added and the mixture stirred for 30 minutes at room temperature. The secondary amine 23 as its TFA salt (73 mg, 0.255 mmol) was added and the reaction stirred for 18 hours. The reaction mixture was diluted with ethyl acetate (20 mL) and added to saturated ammonium chloride (30 mL). The aqueous phase was extracted with ethyl acetate ( $3 \times 10$  mL). The combined organic phases were then washed with water ( $2 \times 5$  mL), 1 N HCl (aq.) (5 mL), saturated sodium bicarbonate solution (aq.) (50 mL), water (5 mL), brine (5 mL) and dried ( $MgSO_4$ ) before concentration *in vacuo* to give the crude product. Flash chromatography eluting with ethyl

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acetate/hexane, 1:1 to give the desired coupled product **26** as a colorless oil. The reaction was followed by oxidation using the general Dess-Martin oxidation procedure as given supra for compound **2** to give the desired product **900**. Flash chromatography eluting with 20% ethyl acetate in hexane gave the  $\alpha$ -keto amide **900** (20 mg, quantitative).  $R_f = 0.63$  (50% EtOAc in hexane). All analysis performed on mixture of isomers: NMR major isomer:  $^1\text{H}$  NMR (400MHz,  $\text{CDCl}_3$ )  $\delta$  7.32-7.17 (10H, m), 5.75 (1H, d,  $J$  8.7), 5.16-5.12 (1H, m), 5.09 (1H, d,  $J$  12.4), 5.04 (1H, d,  $J$  12.4), 4.39 (1H, dt,  $J$  3.9, 8.3), 3.98-3.96 (1H, m), 3.92 (1H, t,  $J$  6.0), 3.82-3.77 (1H, m), 3.73 (1H, dd,  $J$  10.0, 5.0), 3.55 (1H, dd,  $J$  10.0, 2.8), 3.47-3.17 (3H, m), 3.45 (3H, s), 3.40 (3H, s), 3.26 (3H, s), 3.19 (3H, s), 3.11 (1H, dd,  $J$  14.1, 6.92);  $^{13}\text{C}$  NMR (100MHz,  $\text{CDCl}_3$ )  $\delta$  197.62 (C=O), 164.7 (C=O), 155.7 (C=O), 136.4 (C), 129.7 (2 x CH), 128.4 (2 x CH), 128.3 (4 x CH), 127.9 (CH), 126.7 (CH), 84.6 (CH), 83.6 (CH), 70.7 ( $\text{CH}_2$ ), 69.7 ( $\text{CH}_2$ ), 66.8 ( $\text{CH}_2$ ), 60.7 (CH), 58.9 (CH), 58.7 ( $\text{OCH}_3$ ), 58.7 ( $\text{OCH}_3$ ), 58.4 ( $\text{OCH}_3$ ), 58.4 ( $\text{OCH}_3$ ), 56.7 (CH), 37.3 ( $\text{CH}_2$ ) minor isomer:  $^1\text{H}$  NMR (400MHz,  $\text{CDCl}_3$ )  $\delta$  7.32-7.17 (10H, m), 5.46 (1H, d,  $J$  9.0), 5.11-4.87 (3H, m), 4.56-3.17 (10H, m), 3.45 (3H, s), 3.38 (3H, s), 3.31 (3H, s), 3.21 (3H, s). IR (NaCl)  $\nu_{\text{max}}$  2930, 1717, 1635, 1506, 1456, 1110; FABHRMS (NBA/CsI)  $m/e$  661.1550 ([M+Cs] $^+$ ,  $\text{C}_{28}\text{H}_{36}\text{N}_2\text{O}_8$  requires 661.1526).

30 General peptide coupling procedure to form  $\alpha$ -ketoamide from pyrrolidine as illustrated in figure

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12:

As illustrated in figure 12, steps i-ii, the substrate 15 (70 mg, 0.213 mmol), is dissolved in dry DMF (3 mL). HOBT, 1-hydroxybenzotriazole hydrate (31 mg, 0.22 mmol), EDC, 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide, (43 mg, 0.224 mmol), DIEA, diisopropylethylamine, (122  $\mu$ L, 0.703 mmol) are added and the mixture is stirred for 30 minutes at room temperature. The secondary amine 22; 23; 24; 16; 25; 36; 37; 40; 42; 44; 46; 47; 48; 52; 53; 54; 58; 59; 60; 64; 65; 66; 100; 101; 102 or 103 as its TFA salt (73 mg, 0.255 mmol) is added and the reaction stirred for 18 hours. The reaction mixture is diluted with ethyl acetate (20 mL) and added to saturated ammonium chloride (30 mL). The aqueous phase is extracted with ethyl acetate (3 x 10 mL). The combined organic phases are then washed with water (2 x 5 mL), 1 N HCl (aq.) (5 mL), saturated sodium bicarbonate solution (aq.) (50 mL), water (5 mL), brine (5 mL) and dried ( $MgSO_4$ ) before concentration *in vacuo* to give the crude product. Flash chromatography, eluting with 1:1 ethyl acetate/hexane gives the desired coupled product which is directly carried on to the next step for oxidation of the secondary alcohol as follows. The secondary alcohol (21 mg, 0.044 mmol) is dissolved in dry  $CH_2Cl_2$  (2 mL), and Dess-Martin periodinane (26 mg, 0.088 mmol) added. The reaction mixture is stirred at ambient temperature for 24 hours, then diluted with ethyl acetate (10 mL) and quenched by addition of saturated sodium bicarbonate (aq.) (5 mL) and sodium thiosulfate. The aqueous phase is extracted with ethyl acetate (3 x 20 mL).

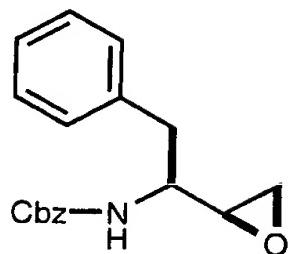
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The combined organic extracts washed with water (10 mL), brine (10 mL), dried ( $\text{MgSO}_4$ ) and concentrated *in vacuo* to give the crude product. Flash chromatography eluting with 30% ethyl acetate in hexane gives the respective product  
5  
70;900;71;2;73;74;75;76;77;78;79a;80a;81a;79b;80b;81b  
;82a;83a;84a;82b;83b;84b;1c;107;108 or 109 as a 3:1 mixture of diastereomers (colorless oil) (20 mg, 95%) as a colorless oil.

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Synthesis of epoxide 21 as shown in figures 11 and 14.



21

5       Compound 21: To a solution of compound 15 in methanol:THF (.10 M; 1:2), at 0 °C, is added a solution boran-dimethyl sulfide (5 equivalents; 1.0 M) and allowed to stir for overnight. The solvent is then removed and the mixture is resuspended in  
10      methylene chloride (.10 M) and 1.2 equivalents of triethylamine is added at 0 °C and allowed to stir for 1 hour. Next, 1.1 equivalents of tosylchloride is added and allowed to stir at 0 °C for an additional hour. The reaction mixture is then  
15      quenched with water, extracted with 100% ethylacetate, washed over bicarbonate, brine and dried over magnesium sulfate. The crude compound is purified by flash chromatography. The compound is then resuspended in MeOH at 0 °C and 10 equivalents  
20      of KCO<sub>3</sub> is added and allowed to stir for one hour. The reaction mixture is then filtered through celite, quenched with water, extracted with 100%

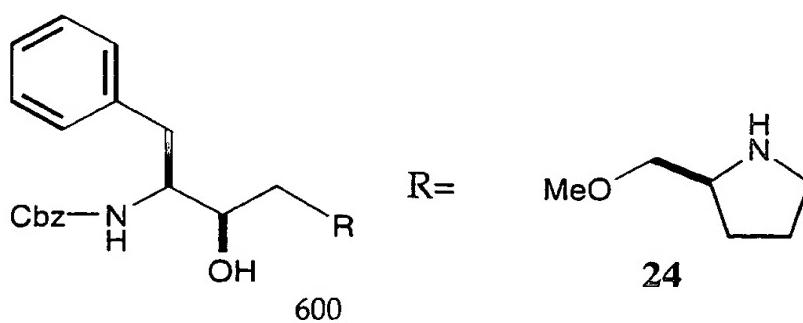
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ethylacetate, washed over bicarbonate, brine and dried over magnesium sulfate. The crude compound is purified by flash chromatography give compound 21.

5 General procedure for coupling of epoxide to proline derivatives as illustrated in figure 11

To the pyrrolidine derivative 22; 23; 24; 16; 25; 36; 37; 40; 42; 44; 46; 47; 48; 52; 53; 54; 58; 59; 60; 10 64; 65; 66; 100; 101; 102 or 103 (20 mg, 0.091 mmol) was added dry methanol (2 mL), Cbz-phenylalanyl epoxide 21 (27 mg, 0.091 mmol, 1.0 eq.) and triethylamine (14  $\mu$ L, 0.100mmol, 1.1eq.). The solution was refluxed for 32 h, and then concentrated 15 in vacuo. Flash chromatography, eluting with ethyl acetate provides the desired product as a clear oil to give respectively hydroxylethyl amine derivatives: 400; 500; 600; 700; 800; 38; 39; 41; 43; 45; 49; 50; 51; 55; 56; 57; 61; 62; 63; 67; 68; 69; 1b; 104; 105; 20 106.

Synthesis of N-[1-Phenyl-2(S)-[(benzyloxycarbonyl)amino]-3(R)-hydroxybutan-4-[2'(R)methoxymethyl]-pyrrolidine 600 as illustrated in figure 11

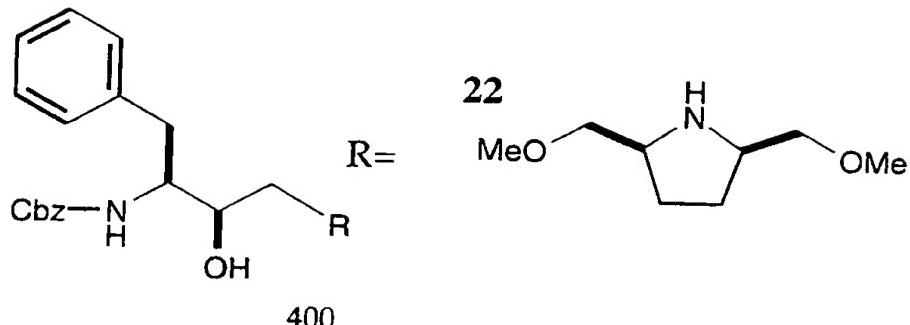


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Compound 600: The pyrrolidine derivative 24 was coupled to the epoxide 21 as described in the general procedure to provide 600. Flash chromatography eluting with ethyl acetate provided the desired product as a clear oil (40 mg, 56%).  $R_f = 0.15$  (EtOAc).  $^1\text{H}$  NMR (400MHz, CD<sub>3</sub>OD)  $\delta$  7.29-7.16 (10H, m), 4.97 (1H, d,  $J$  12.7), 4.92 (1H, d,  $J$  12.7), 3.85-3.81 (1H, m), 3.77-3.73 (1H, m), 3.42-3.25 (3H, m), 3.31 (3H, s), 3.25-3.02 (2H, m), 2.89 (1H, m), 2.64 (1H, dd,  $J$  13.8, 10.5), 2.61-2.52 (2H, m), 1.95-1.87 (1H, m), 1.84-1.77 (2H, m), 1.61-1.55 (1H, m); C<sup>13</sup> NMR (100MHz, CD<sub>3</sub>OD)  $\delta$  158.5 (C=O), 140.3 (2 x C), 130.5 (3 x CH), 129.4 (CH), 129.2 (3 x CH), 128.8 (CH), 128.5 (CH), 127.2 (CH), 73.0 (CH), 67.1 (2 x CH<sub>2</sub>), 59.9 (CH<sub>2</sub>), 59.3 (2 x CH<sub>2</sub>), 57.5 (OCH<sub>3</sub>), 57.2 (CH<sub>2</sub>), 36.8 (CH<sub>2</sub>), 28.5 (CH<sub>2</sub>), 24.2 (CH<sub>2</sub>); IR (NaCl)  $\nu_{\text{max}}$  3330, 2939, 1699, 1538, 1454, 1252, 1203, 1134, 699; FABHRMS (NBA/NaI)  $m/e$  413.2458 ([M+H]<sup>+</sup>, C<sub>24</sub>H<sub>32</sub>N<sub>2</sub>O<sub>4</sub> requires 413.2440).

Synthesis of N-[1-Phenyl-2(S)-[ (benzyloxycarbonyl)amino]-3(R)-hydroxybutan-4-[2'(R), 5'(R)-bis(methoxymethyl)]-pyrrolidine 400 as illustrated in figure 11

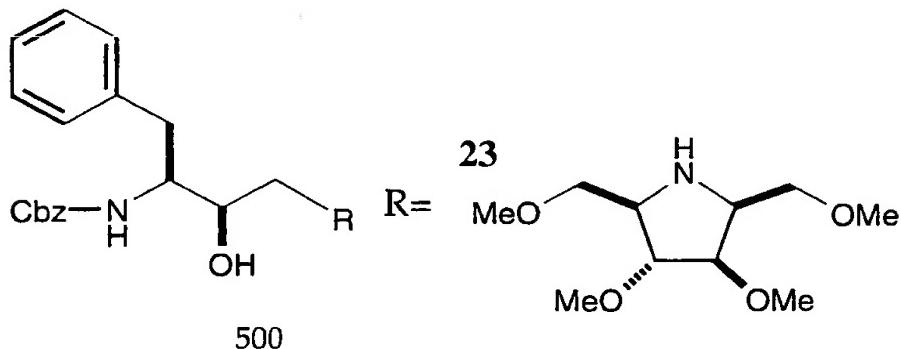
-68-



**Compound 400:** The pyrrolidine derivative 22 (Cignarella, G.; Nathansohn, G. *J. Org. Chem.* 1960, 26, 1500-1502) was coupled, according to the above conditions, to the epoxide 21 to provide 400. Flash chromatography eluting with 30% to 50% ethyl acetate in hexane provided the desired product as a clear oil (35 mg, 40%).  $R_f$  = 0.47 (EtOAc/Hexane, 1:1).  $^1\text{H}$  NMR (400MHz, CDCl<sub>3</sub>)  $\delta$  7.33-7.17 (10H, m), 5.02 (2H, dd,  $J$  20.4, 12.1), 3.89 (1H, m), 3.50 (1H, m), 3.37 (3H, s), 3.31 (2H, d,  $J$  1.1), 3.24 (3H, s), 3.20-3.18 (2H, m), 2.95-2.89 (4H, m), 2.85-2.75 (2H, m), 1.87-1.83 (2H, m), 1.54-1.52 (2H, m);  $^{13}\text{C}$  NMR (100MHz, CDCl<sub>3</sub>)  $\delta$  137.9, 129.6, 128.4, 128.2, 127.9, 127.8, 126.2, 77.5, 76.8, 71.2, 66.6, 66.3, 60.4, 59.0, 58.8, 54.9, 36.2, 29.6; FABHRMS (NBA)  $m/e$  457.2689 ([M+H]<sup>+</sup>C<sub>26</sub>H<sub>36</sub>N<sub>2</sub>O<sub>5</sub> requires 457.2702)

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Synthesis of *N*-[1-Phenyl-2(*S*)-[  
 (benzyloxycarbonyl)amino]-3(*R*)-hydroxybutan-4-  
 [2'(*R*), 5'(*R*)-bis(methoxymethyl)-3'(*R*), 4'(*S*)-  
 dimethoxy]-pyrrolidine 500 as illustrated in figure  
 5 11.



Compound 500: The pyrrolidine derivative 23 was coupled to the epoxide 21 as described above. Flash chromatography eluting with 50% ethyl acetate in hexane gave the desired product 500 as a pale yellow oil (20mg, 42%)  $R_f$  = 0.37 (EtOAc/Hexane, 1:1).

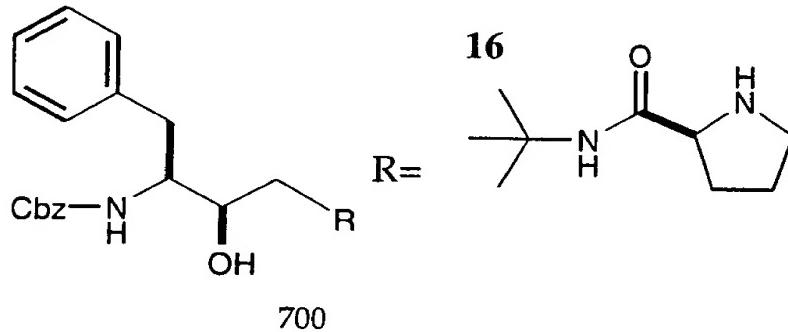
<sup>1</sup>H NMR (400MHz, CDCl<sub>3</sub>)  $\delta$  7.33-7.19 (10H, m), 5.02 (2H, dd, *J* 12.3, 20.6), 4.09 (1H, br s) 3.90 (1H, m), 3.70 (1H, d, *J* 3.7), 3.58 (1H, dd, *J* 6.4, 9.3), 3.54 (2H, m), 3.37 (3H, s), 3.36 (3H, s), 3.35 (3H, s), 3.40-3.28 (5H, m), 3.28 (3H, s), 3.25-3.17 (1H, m), 2.95-2.85 (2H, m), 2.82-2.77 (2H, m); <sup>13</sup>C NMR (100MHz, CDCl<sub>3</sub>)  $\delta$  155.9, 137.9, 129.7, 128.4, 128.3, 127.9, 127.8, 126.3, 84.8, 83.9, 75.1, 72.2, 70.6, 69.9, 66.9, 66.4, 61.0, 59.0, 58.9, 58.0, 57.1, 54.9, 29.7;

-70-

FABHRMS (NBA) *m/e* 517.2932 ([M+H]<sup>+</sup> C<sub>28</sub>H<sub>40</sub>N<sub>2</sub>O<sub>7</sub> requires 517.2914).

**Synthesis of N-[1-Phenyl-2(*S*)-**

5     [(benzyloxycarbonyl)amino]-3(*R*)-hydroxybutan-4-L-prolyl-tert-butyl amide 700 as illustrated in figure 11.



10

**Compound 700:** L-Proline tert-butyl amide 16

(synthesized supra) was coupled according to the above conditions to the epoxide 21 to give 700.

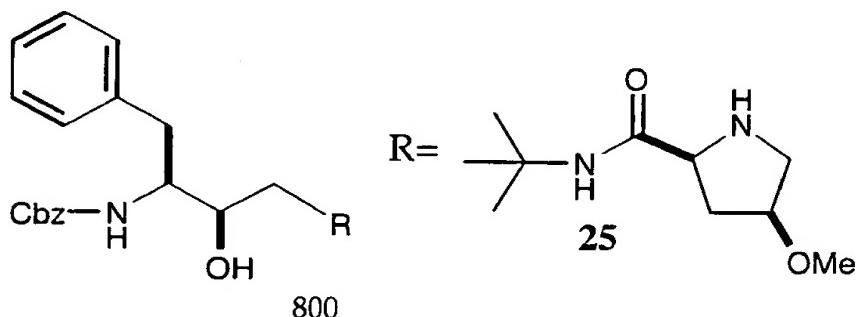
15     Flash chromatography eluting with 100% ethyl acetate in hexane gave the desired product 700 as a colorless oil (70mg, 48%). R<sub>f</sub> = 0.17 (EtOAc/Hexane, 1:1).

20     <sup>1</sup>H NMR (400MHz, CDCl<sub>3</sub>) δ 7.33-7.14 (10H, m), 7.02 (1H, br s), 5.26 (1H, br s), 5.06 (2H, s), 3.93-3.86 (1H, m), 3.67-3.65 (1H, m), 3.29-3.16 (1H, m), 2.90-2.75 (3H, m), 2.67 (1H, d, J 1.7), 2.48 (1H, dd, J 4.8, 2.5), 2.20-2.05 (1H, m), 1.95-1.65 (3H, m), 1.30 (9H,

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s);  $^{13}\text{C}$  NMR (63MHz,  $\text{CDCl}_3$ )  $\delta$  175.7, 174.4, 137.5, 129.2, 128.5, 128.4, 128.0, 127.9, 126.5, 72.1, 68.9, 66.7, 59.8, 56.1, 55.5, 50.4, 35.4, 30.9, 29.6, 28.6, 24.3; FABHRMS (NBA)  $m/e$  468.2810 ( $[\text{M}+\text{H}]^+$ )  $\text{C}_{27}\text{H}_{37}\text{N}_3\text{O}_4$  requires 467.2862).

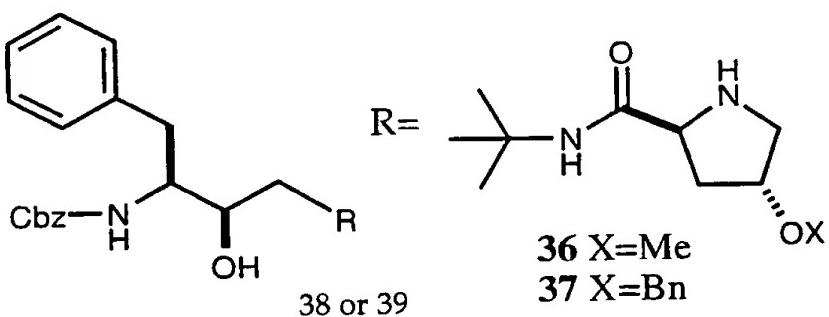
Synthesis of *N*-(1-Phenyl-2(*S*)-[(benzyloxycarbonyl)amino]-3(*R*)-hydroxybutan-4-[2'(*R*)-*(tert*-butylamido)-4'(*S*)-methoxy]pyrrolidine 800 as illustrated in figure 11.



Compound 800: the pyrrolidine derivative 25 (derived from *cis*-4-hydroxy-L-proline) was coupled to the epoxide 21 as described above. Flash chromatography eluting with 50% ethyl acetate in hexane gave the desired product 800 as a pale yellow oil (40mg, 60%)  $R_f = 0.23$  (EtOAc).  $^1\text{H}$  NMR (250MHz,  $\text{CDCl}_3$ )  $\delta$  7.34-7.14 (10H, m), 7.04 (1H, br s), 5.01 (2H, br s,), 4.81 (1H, d,  $J$  8.8), 3.98-3.85 (1H, m), 3.84 (1H, t,  $J$  3.7), 3.58 (1H, dd,  $J$  6.0, 6.1), 3.35-3.25 (1H, m), 3.28 (3H, s), 3.20-3.12 (1H, m), 3.00-2.90 (2H, m),

2.85 (1H, dd, *J* 13.3, 8.1), 2.71 (1H, d, *J* 12.4),  
2.66 (1H, d, *J* 12.4), 2.56 (1H, dd, *J* 10.3, 3.1),  
2.30-2.10 (1H, m), 2.05-1.95 (1H, m), 1.33 (9H, s);  
<sup>13</sup>C NMR (100MHz, CDCl<sub>3</sub>) δ 174.7 (C=O), 172.0 (C=O),  
5 137.5 (C), 129.5 (2 x CH), 129.3 (C), 128.5 (3 x CH),  
128.4 (2 x CH), 128.0 (CH), 127.9 (CH), 126.5 (CH),  
79.9 (CH), 71.4 (CH), 68.3 (CH), 66.6 (C), 60.6  
(CH<sub>2</sub>)<sub>2</sub> 59.7 (CH<sub>2</sub>), 56.0 (CH<sub>3</sub>O), 55.0 (CH), 50.3 (CH<sub>2</sub>),  
35.8 (CH<sub>2</sub>), 29.7 (CH<sub>2</sub>), 28.6 (3 x CH<sub>3</sub>); FABHRMS  
10 (NBA/CsI) *m/e* 630.1970 ([M+Cs]<sup>+</sup> C<sub>28</sub>H<sub>39</sub>N<sub>3</sub>O<sub>5</sub> requires  
630.1944).

Synthesis of *N*-[1-Phenyl-2(*S*)-[(benzyloxy-carbonyl)amino]-3(*R*)-hydroxy-butan-4-[2'-(*S*)-(tert-butyl-amido)-4'(*R*)-methoxy]-pyrrolidine 38  
15 as illustrated in figure 11.



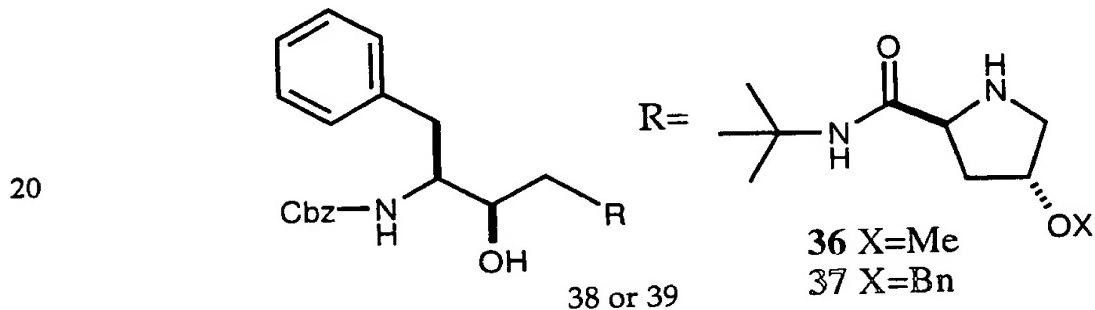
Compound 38: The pyrrolidine derivative 36 (derived from *trans* 4-hydroxy-L-proline) was coupled to the epoxide 21 as described above. Flash chromatography eluting with 75% ethyl acetate in hexanes gave the desired product 38 as a pale yellow oil (45mg, 40%)  
20

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$R_f = 0.20$  (EtOAc/Hexane, 4:1).

$^1\text{H}$  NMR (400MHz,  $\text{CDCl}_3$ )  $\delta$  7.33-7.13 (10H, m), 6.79 (1H, br s), 5.02 (2H, s), 4.89 (1H, d,  $J$  7.5), 3.88-3.85 (2H, m), 3.72-3.61 (1H, m), 3.49-3.33 (1H, m), 3.29 (3H, s), 3.20 (1H, t,  $J$  8.0), 2.97-2.57 (5H, m), 2.29-2.22 (1H, m), 1.95-1.88 (1H, m), 1.67 (1H, br s), 1.31 (9H, s);  $^{13}\text{C}$  NMR (100MHz,  $\text{CDCl}_3$ ) 173.6, 156.5, 137.7, 136.3, 128.9, 128.3, 127.7, 127.6, 126.4, 79.7, 72.0, 68.0, 65.8, 60.2, 59.9, 56.6, 55.5, 50.5, 36.8, 35.3, 28.6; IR (NaCl)  $\nu_{\text{max}}$  3307, 2968, 2932, 2357, 1749, 1713, 1652, 1531, 1455, 1365, 1258, 1230, 1095, 1027, 734, 698; FABHRMS (NBA)  $m/e$  498.2955 ( $[\text{M}+\text{H}]^+$   $\text{C}_{28}\text{H}_{39}\text{N}_3\text{O}_5$  requires 498.2968); Found: C, 67.36; H, 8.30; N 8.49.  $\text{C}_{28}\text{H}_{39}\text{N}_3\text{O}_5$  requires C, 67.57; H, 7.90; N, 8.45).

N-[1-Phenyl-2(S)-[(benzyloxycarbonyl)amino]-3(R)-hydroxybutan-4-[2'(S)-(tert-butylamido-4'(R)-benzyloxy)-pyrrolidine 39 as illustrated in figure 11.

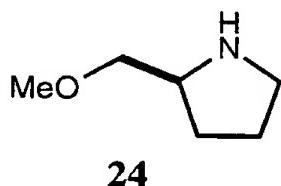


Compound 39: The pyrrolidine derivative 37 (derived from *trans* 4-hydroxy-L-proline) was coupled to the

-74-

epoxide 21 as described above. Flash chromatography eluting with 50% ethyl acetate in hexanes gave the desired product 39 as colorless oil (28mg, 53%)  $R_f = 0.20$  (EtOAc/ Hexane, 1:1).  $^1\text{H}$  NMR (400MHz,  $\text{CDCl}_3$ ) 7.34-7.16 (15H, m), 6.76 (1H, br s), 5.01 (2H, s), 4.85 (1H, d,  $J$  8.2), 4.51 (1H, d,  $J$  11.7), 4.43 (1H, d,  $J$  11.7), 4.13-4.07 (1H, m), 3.90-3.80 (1H, m), 3.70-3.62 (1H, m), 3.50-3.35 (2H, m), 3.24 (1H, t,  $J$  8.0), 2.92-2.68 (4H, m), 2.35-2.29 (1H, m), 1.99-1.93 (1H, m), 1.63 (1H, br s), 1.30 (9H, s);  $^{13}\text{C}$  NMR (100MHz,  $\text{CDCl}_3$ ) 137.5, 129.3, 128.6, 128.5, 128.4, 128.1, 127.9, 127.8, 127.7, 126.6, 80.1, 77.9, 71.1, 68.2, 60.8, 60.1, 55.7, 37.4, 35.9, 29.7, 28.6; IR (NaCl)  $\nu_{\text{max}}$  3307, 2923, 1713, 1652, 1532, 1455, 1365, 1263, 1229, 1097, 1028, 733, 699; FABHRMS (NBA)  $m/e$  706.2288 ( $[\text{M}+\text{Cs}]^+$   $\text{C}_{34}\text{H}_{43}\text{N}_3\text{O}_5$  requires 706.2257).

Synthesis of compound 24 as shown in figure 11; 12



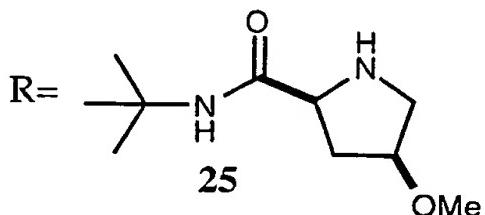
20

**Compound 24:** To a solution of L-proline in methanol:THF (.10 M; 1:2), at 0 °C, is added a solution boran-dimethyl sulfide (5 equivalents; 1.0 M) and allowed to stir for overnight. The solvent is then removed and the mixture is resuspended in methylene chloride (.10 M) and 1.2 equivalents of NaH (30%) is added at 0 °C and allowed to stir for 1 hour. Next, 1.1 equivlanents of methyl iodide is

-75-

5 added and allowed to stir at 0 °C for an additional hour. The reaction mixture is then quenched with water, extracted with 100% ethylacetate, washed over bicarbonate, brine and dried over magnesium sulfate. The crude compound is purified by flash chromatography to give compound **24**.

Synthesis of compound 25 as shown in figure 11; 12

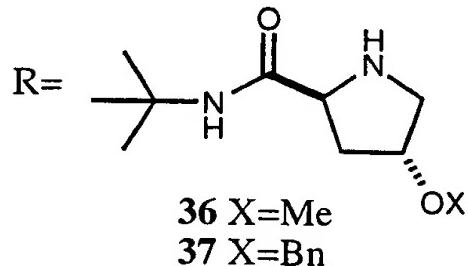


10  
Compound 25: The substrate *cis* 4-hydroxy-L-proline commercially available from Sigma, (3.0 g, 13.9 mmol), was dissolved in dry CH<sub>2</sub>Cl<sub>2</sub> (20 mL). HOBT, 1-hydroxybenzotriazole hydrate (2.07 g, 15.3 mmol), EDC, 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide, (2.93 g, 15.3 mmol), and *tert*-butylamine (1.6 mL, 15.3 mmol), were added and the mixture stirred for 18 hours at ambient temperature. The reaction was diluted with ethyl acetate (100 mL), and washed with water (2 x 20 mL), 1 N HCl (aq.) (10 mL), saturated sodium bicarbonate solution (aq.) (10 mL), water (10 mL), brine (10 mL) and dried (MgSO<sub>4</sub>) before concentration in vacuo to give the crude product. Purification by flash chromatography, eluting with 33% EtOAc in Hexane gave *N*-*tert*-butoxycarbonyl-*cis*-4-hydroxy-L-prolyl-*tert*-butyl amide as a colorless

oil. The compound was then resuspended in methylene chloride (.10 M) and 1.2 equivalents of NaH (30%) is added at 0 °C and allowed to stir for 1 hour. Next, 1.1 equivalents of methyl iodide is added and allowed to stir at 0 °C for an additional hour. The reaction mixture is then quenched with water, extracted with 100% ethyl acetate, washed over bicarbonate, brine and dried over magnesium sulfate. The crude compound is purified by flash chromatography to give compound 25.

10

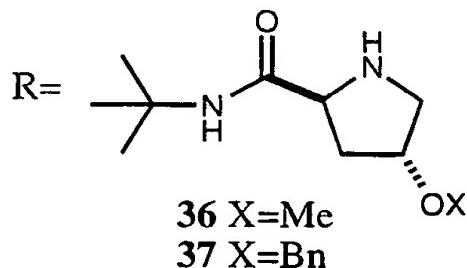
Synthesis of compound 36 as shown in figure 11; 12



**Compound 36:** The substrate *trans*-4-hydroxy-L-proline commercially available from Sigma, (3.0 g, 13.9 mmol), was dissolved in dry  $\text{CH}_2\text{Cl}_2$  (20 mL). HOBT, 1-hydroxybenzotriazole hydrate (2.07 g, 15.3 mmol), EDC, 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide, (2.93 g, 15.3 mmol), and *tert*-butylamine (1.6 mL, 15.3 mmol), were added and the mixture stirred for 18 hours at ambient temperature. The reaction was diluted with ethyl acetate (100 mL), and washed with water (2 x 20 mL), 1 N HCl (aq.) (10 mL), saturated sodium bicarbonate solution (aq.) (10 mL), water (10 mL), brine (10 mL) and dried ( $\text{MgSO}_4$ ) before

concentration in vacuo to give the crude product. Purification by flash chromatography, eluting with 33% EtOAc in Hexane gave *N*-tert-butoxycarbonyl-*trans*-4-hydroxy-L-prolyl-tert-butyl amide as a colorless oil. The compound was then resuspended in methylene chloride (.10 M) and 1.2 equivalents of NaH (30%) is added at 0 °C and allowed to stir for 1 hour. Next, 1.1 equivalents of methyl iodide is added and allowed to stir at 0 °C for an additional hour. The reaction mixture is then quenched with water, extracted with 100% ethylacetate, washed over bicarbonate, brine and dried over magnesium sulfate. The crude compound is purified by flash chromatography to give compound 36.

15           Synthesis of compound 37 as shown in figure 11; 12

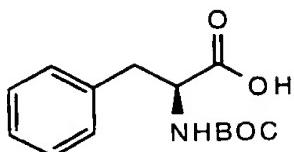


Compound 37: The substrate *trans*- 4-hydroxy-L-proline commercially available from Sigma, (3.0 g, 13.9 mmol), was dissolved in dry CH<sub>2</sub>Cl<sub>2</sub> (20 mL). HOBT, 1-hydroxybenzotriazole hydrate (2.07 g, 15.3 mmol), EDC, 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide, (2.93 g, 15.3 mmol), and tert-butylamine (1.6 mL, 15.3 mmol), were added and the mixture stirred for 18 hours at ambient temperature. The reaction was

diluted with ethyl acetate (100 mL), and washed with water (2 x 20 mL), 1 N HCl (aq.) (10 mL), saturated sodium bicarbonate solution (aq.) (10 mL), water (10 mL), brine (10 mL) and dried ( $MgSO_4$ ) before  
5 concentration in vacuo to give the crude product. Purification by flash chromatography, eluting with 33% EtOAc in Hexane gave *N*-tert-butoxycarbonyl-*trans*-4-hydoroxy-L-prolyl-tert-butyl amide as a colorless oil. The compound was then resuspended in methylene  
10 chloride (.10 M) and 1.2 equivalents of NaH (30%) is added at 0 °C and allowed to stir for 1 hour. Next, 1.1 equivlanents of benzylbromide is added and allowed to stir at 0 °C for an additional hour. The reaction mixture is then quenched with water,  
15 extracted with 100% ethylacetate, washed over bicarbonate, brine and dried over magnesium sulfate. The crude compound is purified by flash chromatography to give compound 37.

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Synthesis of compound 27 (compound is shown in figures 9 and 10)

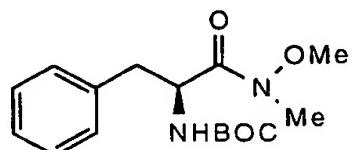


27

5           Compound 27: To a solution of phenylalanine (1.0 equiv.) in acetonitrile (.10 Molar) was added 1.2 equivalents of commercially available BOC-ON [2-(tert-butoxycarbonyloxyimino)-2-phenyl-acetonitrile] and the mixture was allowed to stir for 12 hours at 25 °C. The solvent was then evaporated and the crude compound 27 was carried on to the next step.

10

Synthesis of compound 28 as illustrated in figure 9



94%

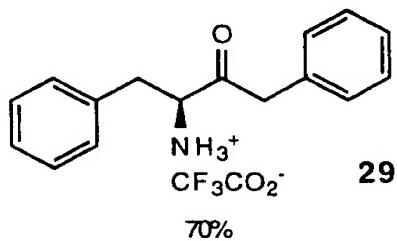
28

15           Compound 28: The substrate 27 (70 mg, 0.213 mmol), was dissolved in dry DMF (3 mL). HOBT, 1-hydroxybenzotriazole hydrate (31 mg, 0.22 mmol), EDC, 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide, (43

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mg, 0.224 mmol), DIEA, diisopropyl-ethylamine, (122 µl, 0.703 mmol) were added and the mixture stirred for 30 minutes at room temperature. The commercially available N-methoxy-methyl amine hydrochloride salt (73 mg, 0.255 mmol; Aldrich) was added and the reaction stirred for 18 hours. The reaction mixture was diluted with ethyl acetate (20 mL) and added to saturated ammonium chloride (30 mL). The aqueous phase was extracted with ethyl acetate (3 x 10 mL).  
5 The combined organic phases were then washed with water (2 x 5 mL), 1 N HCl (aq.) (5 mL), saturated sodium bicarbonate solution (aq.) (50 mL), water (5 mL), brine (5 mL) and dried ( $\text{MgSO}_4$ ) before concentration in vacuo to give the crude product.  
10 Flash chromatography eluting with ethyl acetate/hexane, 1:1 to give the desired coupled product **28** as a colorless oil (94%).  
15

20 **Synthesis of 3(S)-1,4-Diphenyl-2-oxo-3-amino-N-Boc-butane (29)** as illustrated in figure 9

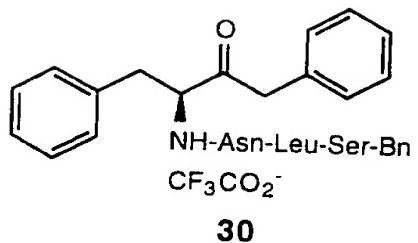


25 **3(S)-1,4-Diphenyl-2-oxo-3-amino-N-Boc-butane (29):**  
To a stirred solution of N-Boc-L-phenylalanine-N-methoxy-N-methylamide (28) (5.0 g, 14.5 mmol) in anhydrous THF (50 mL) under  $\text{N}_2$  at 0°C was added 2.0 M

benzyl magnesium chloride in THF (21.7 mL, 43.5 mmol). The mixture was gradually warmed at room temperature and stirred for an additional 3h. The reaction mixture was then poured onto 1 N HCl (25 mL). The organic layer was separated and the aqueous layer was extracted with ether (3 x 35 mL). The combined organic layers were dried ( $\text{MgSO}_4$ ) and concentrated to give a crude product. Purification of the crude material by flash chromatography (EA:H;1:4) afforded **Boc protected intermediate to 29** as a white solid (4.8 g, 98%).  $R_f$  0.3 (EA:H;1:4); mp 86-87°C;  $[\alpha]^{25D}$  +31.22° (c 2.21,  $\text{CH}_2\text{Cl}_2$ ); IR 3485, 2978, 1709, 1704, 1490, 1363, 1250  $\text{cm}^{-1}$ ;  $^1\text{H}$  NMR ( $\text{CDCl}_3$ ) 1.14 (s, 9H), 2.9-3.15 (m, 2H), 3.65 (q, 2H,  $J=11.6$  Hz), 4.61 (d, 1H,  $J=6.9$  Hz), 5.1 (bs, 1H), 7.0-7.2 (m, 10H) ppm;  $^{13}\text{C}$  NMR ( $\text{CDCl}_3$ ) 28.3, 37.8, 47.8, 59.5, 79.9, 127.0, 127.1, 128.8, 129.2, 129.2, 129.6, 133.1, 135.2, 155.1, 206.5 ppm. HRMS: 472.0880, Calcd for  $\text{C}_{21}\text{H}_{25}\text{NO}_3+\text{Cs}^+$ : 472.0889.

**3(S)-1,4-Diphenyl-2-oxo-3-amino-butane HCl (29):** To a solution of 3(S)-1,4-diphenyl-2-oxo-3-amino-N-Boc-butane (**Boc protected intermediate to 29**) (1.4 g, 4.12 mmol) in ether (10 mL) was added a saturated solution of HCl(g)/Ether (20 mL). After 3 h the precipitate was filtered to afford a crude white solid. Recrystallization (MeOH/Ether) gave 29 as a white solid (0.96 g, 85%).  $^1\text{H}$  NMR (300 MHz,  $\text{CD}_3\text{OD}$ ) 2.96 (dd, 1H,  $J=8.2$  Hz), 3.24 (dd, 1H,  $J=6.2$ , 14.3 Hz), 3.73 (q, 2H,  $J=16.9$  Hz), 4.41 (dd, 1H,  $J=2.0$ , 8.2 Hz) ppm. HRMS: 240.1388 Calcd. for  $\text{C}_{16}\text{H}_{18}\text{NO} + \text{H}^+$ : 240.1388.

Synthesis of Compound 30 as illustrated in figure 9



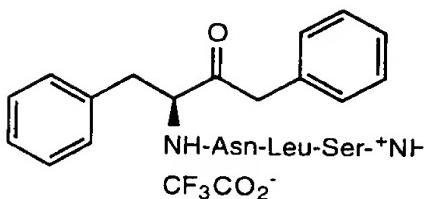
Compound **30**: To a solution of **29** (0.032 g, 0.12 mmol) in CH<sub>2</sub>Cl<sub>2</sub> (10 mL) was added O-benzyl-N-Boc-L-Ser-Leu-Asn (0.075 g, 0.15 mmol), EDC (0.032 g, 0.17 mmol), HOBT (0.045 g, 0.33 mmol) and DMAP (cat.). After 24 h the reaction mixture was washed with sat. NaHCO<sub>3</sub> (2 x 5 mL), 1 N HCl (2 x 5 mL), sat. NaCl (2 x 5 mL), dried (MgSO<sub>4</sub>) and concentrated to give a crude solid. Recrystallization from MeOH/Ether afforded **intermediate N-Boc protected compound to 30** as a white solid (0.05 g, % yield). <sup>1</sup>H NMR (300 MHz, DMSO-d<sub>6</sub>) 0.72-0.85 (m, 6H), 1.35 (s, 9H), 1.50-1.72 (m, 1H), 2.30-2.45 (m, 1H), 2.80-2.90 (m, 1H), 3.05 (dd, 1H, J=5.1, 13.9 Hz), 3.5-3.63 (m, 2H), 3.69 (d, 1H, J=17.0 Hz), 3.86 (d, 1H, J=17.3 Hz), 4.20-4.30 (m, 1H), 4.30-4.45 (m, 1H), 4.46 (s, 2H), 4.48-4.51 (m, 1H), 6.80-7.42 (m, 15H) ppm. HRMS: 876.2955 Calcd for C<sub>41</sub>N<sub>53</sub>N<sub>5</sub>O<sub>8</sub> + CS<sup>+</sup>: 876.2948. Anal Cacl for C<sub>41</sub>H<sub>53</sub>N<sub>5</sub>O<sub>8</sub>: C 60.20%, H 5.615, N 7.18%, S 9.41%. Found C 65.99%, H 7.22%, N 9.61%.

To a solution of **intermediate N-Boc protected compound** (0.12 g, 0.16 mmol) in CH<sub>2</sub>Cl<sub>2</sub> was added a solution of 305 TFA/CH<sub>2</sub>Cl<sub>2</sub>. After 24 h the mixture was concentrated to afford a crude white solid which after recrystallization (MeOH/Ether) afforded the

title compound **30** as a white solid (0.09 g, 75%). <sup>1</sup>H NMR (300 MHz, CD<sub>3</sub>OD) 0.71-0.85 (m, 6H), 1.40-1.60 (m, 3H), 2.40-.262 (m, 2H), 2.70-.291 (m, 1H), 2.91-3.01 (m, 1H), 3.50-3.58 (m, 1H), 3.60-3.72 (m, 2H), 3.75-3.82 (m, 1H), 3.88-4.00 (m, 1H), 4.20-4.30 (m, 1H), 4.44-4.61 (m, 2H), 6.93-7.45 (m, 15H) ppm. HRMS:  
5 644.3448 Calcd for C<sub>36</sub>H<sub>46</sub>N<sub>5</sub>O<sub>6</sub> + H<sup>+</sup>: 644.3448.

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Synthesis of Compound 31 as illustrated in figure 9

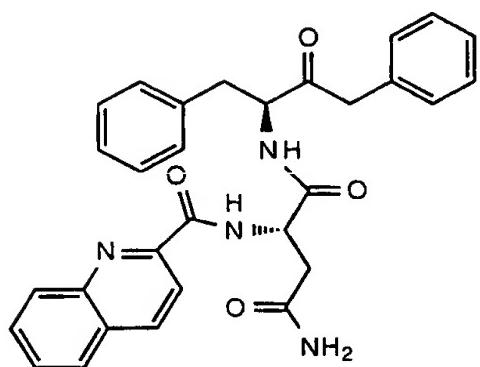


31

Compound 31: A solution of 30 (80 mg, 0.11 mmol) in glacial acetic (10 mL) containing Pd(OH)<sub>2</sub>/C (cat.) was placed under a H<sub>2</sub> atmosphere at 50 psi. After 12 h the solution was filtered and the crude solid was recrystallized from MeOH/Ether to afford the title compound (15 mg, 22%). <sup>1</sup>H NMR (300 MHz, CD<sub>3</sub>OD) 0.82 (t, 6H, J=6.6 Hz), 1.39 (t, 2H, J=7.2 Hz), 1.50-1.60 (m, 1H), 2.36 (dd, 1H, J=8.1, 15.6 Hz), 2.44-2.50 (m, 1H), 2.38 (dd, 1H, J=4.5, 13.9 Hz), 3.05 (dd, 1H, J=4.9, 13.9 Hz), 3.69 (d, 1H, J=17.3 Hz), 3.85 (dd, 1H, J=17.2 Hz), 4.28-4.32 (m, 1H), 4.35-4.42 (m, 1H), 4.48-4.53 (m, 1H), 6.80-7.35 (m, 10H) ppm. HRMS: 686.1961 Calcd for C<sub>31</sub>H<sub>43</sub>N<sub>5</sub>O<sub>8</sub> + CS<sup>+</sup>: 686.1955.

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Synthesis of Compound 32 as illustrated in figure 9

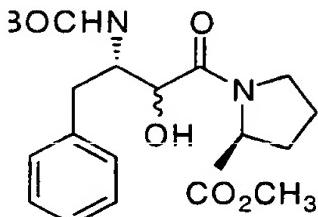


32

Compound 32: To a solution of **29** (0.17 g, 0.62 mmol) in DMF (5 mL) was added HOBr (0.17, 1.2 mmol), DMAP (cat.), EDC (0.12 g, 0.62 mmol), Et<sub>3</sub>N (0.06 g, 0.09 mL, 0.62 mmol) and quinolinic-Asn (g, 0.52 mmol). After 12 h the reaction mixture was taken up in EA (50 mL). The organic layer was dried (MgSO<sub>4</sub>) and concentrated to give a crude brown solid. Recrystallization from MeOH/ether gave a white solid as **32** (0.12 g, 43%). <sup>1</sup>H NMR (300 MHz, DMSO-d<sub>6</sub>) 2.62 (dd, 1H, J=4.9, 15.3 Hz), 2.75 (dd, 1H, J=6.9, 15.5 Hz), 2.84 (dd, 1H, J=14.3, 23.4 Hz), 3.06 (dd, 1H, J=4.6, 13.7 Hz), 3.76 (d, 1H, J=17.0 Hz), 3.91 (d, 1H, J=17.0 Hz), 4.51 (q, 1H, J=7.7 Hz), 4.82 (q, 1H, J=6.8 Hz), 6.95-7.32 (m, 11H), 7.48 (s, 1H), 7.73 (t, 1H, J=7.1 Hz), 7.89 (t, 1H, J=8.3 Hz), 8.13 (q, eH, J=8.7 Hz), 8.58 (t, 2H, J=6.7 Hz) ppm. HRMS:

641.1166 Calcd for  $C_{30}H_{28}NO_4$  +  $Cs^+$ : 641.1165.

Synthesis of Compound 34 as illustrated in figure 10



34

5                   Compound 34: To a solution of compound 33 (7:3 mixture) (0.21 g, 0.71 mmol), as previously prepared from 27 (Yuan, W.; Munoz, B.; Wong, C.-H.; Haeggstrom, J.Z.; Wetterholm, A.; Samuelsson, B. *J. Med. Chem.* 1993, 36, 211) in  $CH_2Cl_2$  (10 mL) was added 10 L-proline methyl ester HCl (0.18 g, 1.1 mmol), EDC (0.16 g, 0.85 mmol), HOBr (0.21 g, 1.56 mmol) and DMAP (cat.). After 24 h the reaction mixture was washed with sat.  $NaHCO_3$  (2 x 2 mL), 1 N HCl (2 x 2 mL) and sat. NaCl (1 x 1 mL). The organic layer was dried ( $MgSO_4$ ), filtered and concentrated to give a crude solid. Purification by flash chromatography (EA:H; 1:4) gave the white solid compound 34 as a 15 single (2R, 3S) (0.23 g, 80%).  $R_f=0.20$  (EA:H;1:4);  $^1H$  NMR (300 MHz,  $CDCl_3$ ) 1.34 (s, 9H), 1.90-2.11 (m, 4H), 2.88-2.91 (m, 2H), 3.11-3.20 (m, 1H), 3.36 (q, 1H,  $J=7.6$  Hz), 3.65 (s, 3H), 3.89 (d, 1H,  $J=5.1$  Hz), 4.08 (d, 1H,  $J=5.7$  Hz), 4.15 (q, 1H,  $J=9.7$  Hz), 4.39 (d, 1H,  $J=7.4$  Hz), 4.89 (d, 1H,  $J=9.9$  Hz), 7.10-7.35 (m,

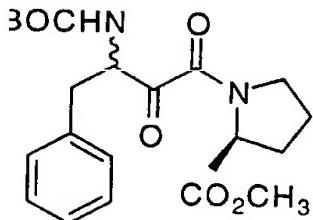
20

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5H) ppm. HRMS: 539.1169 Calcd for  $C_{21}H_{30}N_2O_6 + Cs^+$ :  
539.1158.

Synthesis of Compound 35 as illustrated in figure 10

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35  
65%

Compound 35: To a solution of compound 34 (0.062 g, 0.15 mmol) in anhydrous  $CH_2Cl_2$ , under  $N_2$  at room temperature was added the Dess-Martin reagent (0.078 g, 0.18 mmol). After 12 h the reaction was quenched with sat.  $NaHCO_3$  (4 mL) and sat.  $Na_2S_2O_3$  (4 mL). Ether (40 mL) was added to the reaction and then stirred for 10 min. The reaction mixture was washed with sat.  $NaCl$  ( $2 \times 10$  mL), dried ( $MgSO_4$ ), filtered and concentrated to give a crude oil. Purification by flash chromatography (EA:H; 1:3) afforded compound 35 as a 1:0.8 mixture of an oil (0.030 g, 65%).  $^1H$  NMR (300 MHz,  $CDCl_3$ ) 1.35; 1.35 (s;s, 9H), 1.91-2.01 (m, 3H), 2.15-2.23 (m, 1H), 3.09-3.41 (m, 1H), 3.51-3.70 (m, 2H), 3.70 (m, 2H), 3.70 (q, 3H,  $J=6.3, 7.8$  Hz), 4.40-4.49 (m, 1H), 4.72d-4.85 (m, 1H), 4.93-5.00 (m, 1H), 5.10-5.23 (m, 1H), 7.05-7.35 (m, 5H) ppm. HRMS: 537.1002 Calcd for  $C_{21}H_{28}N_2O_6 + Cs^+$ : 537.1002.

General peptide coupling procedure to form  $\alpha$ -ketoamide from piperidine as illustrated in figure 13:

As illustrated in figure 13, steps i-ii, the substrate 15 (70 mg, 0.213 mmol), is dissolved in dry DMF (3 mL). HOBT, 1-hydroxybenzotriazole hydrate (31 mg, 0.22 mmol), EDC, 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide, (43 mg, 0.224 mmol), DIEA, diisopropylethylamine, (122  $\mu$ L, 0.703 mmol) are added and the mixture is stirred for 30 minutes at room temperature. The secondary amine 85;86;87;88;89;90;91;92;93;94;95;96 or 97 as its TFA salt (73 mg, 0.255 mmol) is added and the reaction stirred for 18 hours. The reaction mixture is diluted with ethyl acetate (20 mL) and added to saturated ammonium chloride (30 mL). The aqueous phase is extracted with ethyl acetate (3 x 10 mL). The combined organic phases are then washed with water (2 x 5 mL), 1 N HCl (aq.) (5 mL), saturated sodium bicarbonate solution (aq.) (50 mL), water (5 mL), brine (5 mL) and dried ( $MgSO_4$ ) before concentration *in vacuo* to give the crude product. Flash chromatography, eluting with 1:1 ethyl acetate/hexane gives the desired coupled product which is directly carried on to the next step for oxidation of the secondary alcohol as follows. The secondary alcohol (21 mg, 0.044 mmol) is dissolved in dry  $CH_2Cl_2$  (2 mL), and Dess-Martin periodinane (26 mg, 0.088 mmol) added. The reaction mixture is stirred at ambient temperature for 24 hours, then diluted with ethyl acetate (10 mL) and quenched by addition of saturated sodium bicarbonate (aq.) (5 mL) and sodium thiosulfate. The aqueous phase is

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extracted with ethyl acetate (3 x 20 mL). The combined organic extracts washed with water (10 mL), brine (10 mL), dried ( $MgSO_4$ ) and concentrated *in vacuo* to give the crude product. Flash chromatography eluting with 30% ethyl acetate in hexane gives the respective product 98; 99; 120; 121; 122; 123; 124; 125; 126; 127; 128; 129 or 130 as a 3:1 mixture of diastereomers (colorless oil) (20 mg, 95%) as a colorless oil.

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**General procedure for coupling of epoxide to proline derivatives as illustrated in figure 14**

To the pyrrolidine derivative

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85; 86; 87; 88; 89; 90; 91; 92; 93; 94; 95; 96 or 97 (20 mg, 0.091 mmol) was added dry methanol (2 mL), Cbz-phenylalanyl epoxide 21 (27 mg, 0.091 mmol, 1.0 eq.) and triethylamine (14  $\mu$ L, 0.100mmol, 1.1eq.). The solution was refluxed for 32 h, and then concentrated *in vacuo*. Flash chromatography, eluting with ethyl acetate provides the desired product as a clear oil to give respectively hydroxylethyl amine derivatives: 131; 132; 133; 134; 135; 136; 137; 138; 139; 140; 141; 142 or 143.

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**Synthesis of compound 1001 as illustrated in Figure 15:** A typical acylation is as follows: Compound 1000 (0.16 mmol; *cis*-dihydroxymethyl-pyrrolidine from Aldrich followed by standard BOC protection; *vida supra*), the vinyl acetate (0.05 mL; Aldrich), DMF (0.2 mL; other solvents such as methylene chloride, chloroform, acetonitrile, tert-butyl alcohol, 3-methyl-3-pentanol, DMSO and THF can also be used),

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H<sub>2</sub>O (0.005 mL), triethylamine (0.005 mL) and  
subtilisin BPN' or subtilisin Carlsberg (5 mg, 50U)  
is stirred at 37°C for 36 h. The reaction is worked  
up by adding EtOAc and filtering the reaction mixture  
5 through celite. The filtrate is washed with sat.  
NaHCO<sub>3</sub> solution, then with brine, dried over MgSO<sub>4</sub> and  
concentrated *in vacuo* to give an oil. Some of the  
product, if possible, is crystallized out at this  
stage by addition of diisopropyl ether. The mother  
10 liquor is then chromatographed (SiO<sub>2</sub>, hexane/EtOAc,  
9/1-1/1) to give the product 1001.

**Synthesis of compound 1002 as illustrated in Figure 15:** Compound 1002 was dissolved in 0.10 Molar  
15 solution of acetone and then 1.5 M sulfuric acid was  
added at 0 °C. Next chromium (VI) oxide (1.1  
equivalents; Aldrich) was added and the mixture was  
allowed to stir for 2 hours. The reaction is worked  
up by adding EtOAc and washed with sat. NaHCO<sub>3</sub>  
20 solution, then with brine, dried over MgSO<sub>4</sub> and  
concentrated *in vacuo* to give an oil. The mother  
liquor is then chromatographed to give the product  
1002.

**Synthesis of compound 1003 as illustrated in Figure 15:** The substrate 1002 (70 mg, 0.213 mmol), is  
dissolved in dry methylene chloride (3 mL). EDC, 1-  
30 (3-dimethylaminopropyl)-3-ethylcarbodiimide, (43 mg,  
0.224 mmol) is added and the mixture is stirred for  
30 minutes at room temperature. *tert*-butyl amine (73  
mg, 0.255 mmol) is added and the reaction stirred for  
18 hours. The reaction mixture is diluted with ethyl  
acetate (20 mL) and added to saturated ammonium

chloride (30 mL). The aqueous phase is extracted with ethyl acetate (3 x 10 mL). The combined organic phases are then washed with water (2 x 5 mL), 1 N HCl (aq.) (5 mL), saturated sodium bicarbonate solution (aq.) (50 mL), water (5 mL), brine (5 mL) and dried ( $MgSO_4$ ) before concentration *in vacuo* to give the crude product. Flash chromatography, eluting with 1:1 ethyl acetate/hexane gives the desired coupled product.

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**Synthesis of compound 1004 as illustrated in Figure 15:** Compound 1003 was dissolved in 0.10 Molar solution of methanol and then 0.10 equivalents sodium methoxide was added at 0 °C and the mixture was allowed to stir for 2 hours. The reaction is concentrated *in vacuo* to give an oil. The mother liquor is then chromatographed to give the product 1004.

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**Synthesis of compound 1005 as illustrated in Figure 15:** Compound 1004 (290 mg, 1.09 mmol; Aldrich) in methylene chloride (2 mL) at 0 °C under argon was added NaH (60% disp. in mineral oil) (96 mg, 2.40 mmol, 2.2 eq.). The mixture was allowed to stir for 20 min., and then benzyl bromide or methyl iodide (0.14 mL, 1.20 mmol, 1.1 eq.) was added. The mixture was allowed to stir for 1 hr at 0°C and then quenched with a few drops of water. Saturated  $NaHCO_3$  solution was added (10 mL) and the aqueous layer was washed with ethyl ether. The aqueous layer was then acidified to pH 2 with 1N HCl, extracted with ethyl acetate (3 x 20 mL), dried over  $MgSO_4$ , and

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concentrated to afford a yellow oil. The mother liquor is then chromatographed to give the product 1005.

5       **Synthesis of compound 46; 47 or 48 as illustrated in Figure 15:** Compound 46; 47 or 48: To a solution of CBZ-protected amine (0.092 mmol) in MeOH (2 mL) was added 20% palladium hydroxide on carbon (10 mg) and the suspension was stirred vigorously under a balloon  
10      of hydrogen at ambient temperature. After 5 min., TLC indicated that the reaction was complete. The suspension was filtered through a pad of celite and concentrated in vacuo to yield product.

15       **Synthesis of compound 1007 as illustrated in Figure 16:** A typical acylation is as follows: Compound 1006 (0.16 mmol; trans-dihydroxymethyl-pyrolidine from Aldrich followed by standard BOC protection; 20      vida supra), the vinyl acetate (0.05 mL; Aldrich), DMF (0.2 mL; other solvents such as methylene chloride, chloroform, acetonitrile, tert-butyl alcohol, 3-methyl-3-pentanol, DMSO and THF can also be used), H<sub>2</sub>O (0.005 mL), triethylamine (0.005 mL) and subtilisin BPN' or subtilisin Carlsberg (5 mg, 25      50U) is stirred at 37°C for 36 h. The reaction is worked up by adding EtOAc and filtering the reaction mixture through celite. The filtrate is washed with sat. NaHCO<sub>3</sub> solution, then with brine, dried over MgSO<sub>4</sub> and concentrated in vacuo to give an oil. Some 30      of the product, if possible, is crystallized out at this stage by addition of diisopropyl ether. The mother liquor is then chromatographed (SiO<sub>2</sub>,

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hexane/EtOAc, 9/1-1/1) to give the product 1007.

**Synthesis of compound 1008 as illustrated in Figure**

16: Compound 1008 was dissolved in 0.10 Molar solution of acetone and then 1.5 M sulfuric acid was added at 0 °C. Next chromium (VI) oxide (1.1 equivalents; Aldrich) was added and the mixture was allowed to stir for 2 hours. The reaction is worked up by adding EtOAc and washed with sat. NaHCO<sub>3</sub> solution, then with brine, dried over MgSO<sub>4</sub> and concentrated *in vacuo* to give an oil. The mother liquor is then chromatographed to give the product 1008.

**Synthesis of compound 1009 as illustrated in Figure**

16: The substrate 1008 (70 mg, 0.213 mmol), is dissolved in dry methylene chloride (3 mL). EDC, 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide, (43 mg, 0.224 mmol) is added and the mixture is stirred for 30 minutes at room temperature. *tert*-butyl amine (73 mg, 0.255 mmol) is added and the reaction stirred for 18 hours. The reaction mixture is diluted with ethyl acetate (20 mL) and added to saturated ammonium chloride (30 mL). The aqueous phase is extracted with ethyl acetate (3 x 10 mL). The combined organic phases are then washed with water (2 x 5 mL), 1 N HCl (<sub>aq.</sub>) (5 mL), saturated sodium bicarbonate solution (<sub>aq.</sub>) (50 mL), water (5 mL), brine (5 mL) and dried (MgSO<sub>4</sub>) before concentration *in vacuo* to give the crude product. Flash chromatography, eluting with 1:1 ethyl acetate/hexane gives the desired coupled product.

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Synthesis of compound 1010 as illustrated in Figure 16: Compound 1009 was dissolved in 0.10 Molar solution of methanol and then 0.10 equivalents sodium methoxide was added at 0 ° C and the mixture was allowed to stir for 2 hours. The reaction is concentrated *in vacuo* to give an oil. The mother liquor is then chromatographed to give the product 1010.

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Synthesis of ( $\pm$ ) compound 1011 as illustrated in Figure 16: Compound 1010 (290 mg, 1.09 mmol; Aldrich) in methylene chloride (2 mL) at 0 °C under argon was added NaH (60% disp. in mineral oil) (96 mg, 2.40 mmol, 2.2 eq.). The mixture was allowed to stir for 20 min., and then benzyl bromide or methyl iodide (0.14 mL, 1.20 mmol, 1.1 eq.) was added. The mixture was allowed to stir for 1 hr at 0°C and then quenched with a few drops of water. Saturated NaHCO<sub>3</sub> solution was added (10 mL) and the aqueous layer was washed with ethyl ether. The aqueous layer was then acidified to pH 2 with 1N HCl, extracted with ethyl acetate (3 x 20 mL), dried over MgSO<sub>4</sub>, and concentrated to afford a yellow oil. The mother liquor is then chromatographed to give the product 1011.

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Synthesis of compound 52; 53 or 54 as illustrated in Figure 16: Compound 52; 53 or 54: To a solution of CBZ-protected amine ( 0.092 mmol) in MeOH (2 mL) was added 20% palladium hydroxide on carbon (10 mg) and the suspension was stirred vigorously under a balloon of hydrogen at ambient temperature. After 5 min.,

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TLC indicated that the reaction was complete. The suspension was filtered through a pad of celite and concentrated in vacuo to yield product.

5       **Synthesis of compound 1013 as illustrated in Figure 17:** Compound 1012 (290 mg, 1.09 mmol; Aldrich) in methylene chloride (0.10 Molar) at 0 °C under argon was added sodium hydroxide (0.10 equivalents), followed by CBZ-Cl (1.1 equivalents; Aldrich) and the mixture was stirred at 0 °C for 20 min. and then quenched with a few drops of water. Saturated ammonium chloride solution was added (10 mL) and the aqueous layer was washed with ethyl ether. The aqueous layer was then neutralized with saturated sodium bicarbonate solution, extracted with ethyl acetate (3 x 20 mL), dried over MgSO<sub>4</sub>, and concentrated to afford a yellow oil. The mother liquor is then chromatographed to give the product 1013.

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20       **Synthesis of compound 1014 as illustrated in Figure 17:** To a solution of substrate 1013 (0.5 mmol) in anhydrous DMF (5 mL) was added TBDPSCl (1.05eq: Aldrich), Et<sub>3</sub>N (1.1 eq), and a catalytic amount of imidazole. The solution was stirred at ambient temperature for 15 hr and then was partitioned between EtOAc (60 mL) and H<sub>2</sub>O (30 mL). The organic layer was then washed with sat'd NH<sub>4</sub>Cl<sub>(aq.)</sub> solution (2 x 30 mL), water (30 mL), brine (30 mL), dried over MgSO<sub>4</sub>, and concentrated in vacuo to yield product. The mother liquor is then chromatographed to give the product 1014.

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**Synthesis of compound 1015 as illustrated in Figure 17:** To a solution of substrate 1014 (0.5 mmol) in anhydrous pyridine (5 mL) was added acetic anhydride (1.05eq: Aldrich). The solution was stirred at ambient temperature for 15 hr and then was partitioned between EtOAc (60 mL) and H<sub>2</sub>O (30 mL). The organic layer was then washed with sat'd NH<sub>4</sub>Cl<sub>(aq.)</sub> solution (2 x 30 mL), water (30 mL), brine (30 mL), dried over MgSO<sub>4</sub>, and concentrated *in vacuo* to yield product. The mother liquor is then chromatographed to give the product 1015.

**Synthesis of compound 1016 as illustrated in Figure 17:** The substrate was dissolved in THF and cooled to 0°C. TBAF (1.0 M solution in THF) was added (1.05 eq.) and the reaction monitored by TLC. After 30 min. at 0°C, the reaction was complete and the solvent was evaporated under reduced pressure. The crude material was applied to a short column of silica gel and eluted to give the product.

**Synthesis of compound 1017 as illustrated in Figure 17:** Compound 1016 was dissolved in 0.10 Molar solution of acetone and then 1.5 M sulfuric acid was added at 0 °C. Next chromium (VI) oxide (1.1 equivalents; Aldrich) was added and the mixture was allowed to stir for 2 hours. The reaction is worked up by adding EtOAc and washed with sat. NaHCO<sub>3</sub> solution, then with brine, dried over MgSO<sub>4</sub> and concentrated *in vacuo* to give an oil. The mother liquor is then chromatographed to give the product 1017.

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Synthesis of compound 1018 as illustrated in Figure 17: The substrate 1017 (70 mg, 0.213 mmol), is dissolved in dry methylene chloride (3 mL). EDC, 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide, (43 mg, 0.224 mmol) is added and the mixture is stirred for 30 minutes at room temperature. tert-butyl amine (73 mg, 0.255 mmol) is added and the reaction stirred for 18 hours. The reaction mixture is diluted with ethyl acetate (20 mL) and added to saturated ammonium chloride (30 mL). The aqueous phase is extracted with ethyl acetate (3 x 10 mL). The combined organic phases are then washed with water (2 x 5 mL), 1 N HCl (aq.) (5 mL), saturated sodium bicarbonate solution (aq.) (50 mL), water (5 mL), brine (5 mL) and dried ( $MgSO_4$ ) before concentration in vacuo to give the crude product. Flash chromatography, eluting with 1:1 ethyl acetate/hexane gives the desired coupled product.

Synthesis of compound 44 as illustrated in Figure 17:  
Step (1) Compound 1018 was dissolved in 0.10 Molar solution of methanol and then 0.10 equivalents sodium methoxide was added at 0 ° C and the mixture was allowed to stir for 2 hours. The reaction is concentrated in vacuo to give an oil. The mother liquor is then chromatographed to give the CBZ-protected amine. Step (2) To a solution of CBZ-protected amine (0.092 mmol) in MeOH (2 mL) was added 20% palladium hydroxide on carbon (10 mg) and the suspension was stirred vigorously under a balloon of hydrogen at ambient temperature. After 5 min., TLC indicated that the reaction was complete. The

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suspension was filtered through a pad of celite and concentrated in vacuo to yield product compound 44.

Synthesis of compound 1019 as illustrated in Figure 18: Compound 1012 (290 mg, 1.09 mmol; Aldrich) in methylene chloride (0.10 Molar) at 0 °C under argon was added sodium hydroxide (0.10 equivalents), followed by CBZ-Cl (1.1 equivalents; Aldrich) and the mixture was stirred at 0 °C for 20 min. and then quenched with a few drops of water. Saturated ammonium chloride solution was added (10 mL) and the aqueous layer was washed with ethyl ether. The aqueous layer was then neutralized with saturated sodium bicarbonate solution, extracted with ethyl acetate (3 x 20 mL), dried over MgSO<sub>4</sub>, and concentrated to afford a yellow oil. The mother liquor is then chromatographed to give the product 1019.

Synthesis of compound 1020 as illustrated in Figure 18: To a solution of substrate 1019 (0.5 mmol) in anhydrous DMF (5 mL) was added TBDPSCl (1.05eq: Aldrich), Et<sub>3</sub>N (1.1 eq), and a catalytic amount of imidazole. The solution was stirred at ambient temperature for 15 hr and then was partitioned between EtOAc (60 mL) and H<sub>2</sub>O (30 mL). The organic layer was then washed with sat'd NH<sub>4</sub>Cl<sub>(aq.)</sub> solution (2 x 30 mL), water (30 mL), brine (30 mL), dried over MgSO<sub>4</sub>, and concentrated in vacuo to yield product. The mother liquor is then chromatographed to give the product 1020.

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Synthesis of compound 1021 as illustrated in Figure 18: To an ice-cooled solution of substrate (0.2 mmol) in anhydrous DMF (2 mL) under argon was added NaH (60% disp. in mineral oil) (2.2 eq.). The mixture was allowed to stir for 20 min., and then methyl iodide or benzyl bromide (1.1 eq.) was added. The mixture was allowed to stir for 1 hr at 0°C and then quenched with a few drops of water. Saturated NaHCO<sub>3</sub> solution was added (10 mL) and the aqueous layer was washed with ethyl ether. The aqueous layer was then acidified to pH 2 with 1N HCl, extracted with ethyl acetate (3 x 20 mL), dried over MgSO<sub>4</sub>, and concentrated to afford product. The mother liquor is then chromatographed to give the product 1021.

Synthesis of compound 1022 as illustrated in Figure 18: The substrate was dissolved in THF and cooled to 0°C. TBAF (1.0 M solution in THF) was added (1.05 eq.) and the reaction monitored by TLC. After 30 min. at 0°C, the reaction was complete and the solvent was evaporated under reduced pressure. The crude material was applied to a short column of silica gel and eluted to give the product.

Synthesis of compound 1023 as illustrated in Figure 18: Compound 1022 was dissolved in 0.10 Molar solution of acetone and then 1.5 M sulfuric acid was added at 0 °C. Next chromium (VI) oxide (1.1 equivalents; Aldrich) was added and the mixture was allowed to stir for 2 hours. The reaction is worked up by adding EtOAc and washed with sat. NaHCO<sub>3</sub> solution, then with brine, dried over MgSO<sub>4</sub> and concentrated in vacuo to give an oil. The mother

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liquor is then chromatographed to give the product 1023.

- 5       **Synthesis of compound 1024 as illustrated in Figure 18:** The substrate 1023 (70 mg, 0.213 mmol), is dissolved in dry methylene chloride (3 mL). EDC, 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide, (43 mg, 0.224 mmol) is added and the mixture is stirred for  
10      30 minutes at room temperature. *tert*-butyl amine (73 mg, 0.255 mmol) is added and the reaction stirred for 18 hours. The reaction mixture is diluted with ethyl acetate (20 mL) and added to saturated ammonium chloride (30 mL). The aqueous phase is extracted  
15      with ethyl acetate (3 x 10 mL). The combined organic phases are then washed with water (2 x 5 mL), 1 N HCl (aq.) (5 mL), saturated sodium bicarbonate solution (aq.) (50 mL), water (5 mL), brine (5 mL) and dried ( $MgSO_4$ ) before concentration in vacuo to give  
20      the crude product. Flash chromatography, eluting with 1:1 ethyl acetate/hexane gives the desired coupled product.
- 25       **Synthesis of compound 40 as illustrated in Figure 18:** CBZ-protected amine 1024 (0.092 mmol) was dissolved in MeOH (2 mL) and 20% palladium hydroxide on carbon (10 mg) was added and the suspension was stirred vigorously under a balloon of hydrogen at ambient temperature. After 5 min., TLC indicated that the reaction was complete. The suspension was filtered through a pad of celite and concentrated in vacuo to yield product compound 40.

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Synthesis of compound 1025 as illustrated in Figure 19: Compound 1025 (290 mg, 1.09 mmol; Aldrich) in methylene chloride (0.10 Molar) at 0 °C under argon was added BOC-ON (1.1 equivalents; Aldrich) and the mixture was stirred at 0 °C for 20 min. and then quenched with a few drops of water. Saturated ammonium chloride solution was added (10 mL) and the aqueous layer was washed with ethyl ether. The aqueous layer was then neutralized with saturated sodium bicarbonate solution, extracted with ethyl acetate (3 x 20 mL), dried over MgSO<sub>4</sub>, and concentrated to afford a yellow oil. The mother liquor is then chromatographed to give the product 1025.

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Synthesis of compound 1026 as illustrated in Figure 19: To a solution of substrate 1025 (0.5 mmol) in anhydrous DMF (5 mL) was added TBDPSCl (1.05eq: Aldrich), Et<sub>3</sub>N (1.1 eq), and a catalytic amount of imidazole. The solution was stirred at ambient temperature for 15 hr and then was partitioned between EtOAc (60 mL) and H<sub>2</sub>O (30 mL). The organic layer was then washed with sat'd NH<sub>4</sub>Cl<sub>(aq.)</sub> solution (2 x 30 mL), water (30 mL), brine (30 mL), dried over MgSO<sub>4</sub>, and concentrated in vacuo to yield product. The mother liquor is then chromatographed to give the product 1026.

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Synthesis of compound 1027 as illustrated in Figure 19: To an ice-cooled solution of substrate (0.2 mmol) in anhydrous DMF (2 mL) under argon was added NaH (60% disp. in mineral oil) (2.2 eq.). The mixture

was allowed to stir for 20 min., and then methyl iodide or benzyl bromide (1.1 eq.) was added. The mixture was allowed to stir for 1 hr at 0°C and then quenched with a few drops of water. Saturated NaHCO<sub>3</sub> solution was added (10 mL) and the aqueous layer was washed with ethyl ether. The aqueous layer was then acidified to pH 2 with 1N HCl, extracted with ethyl acetate (3 x 20 mL), dried over MgSO<sub>4</sub>, and concentrated to afford product. The mother liquor is then chromatographed to give the product 1027.

Synthesis of compound 1028 as illustrated in Figure 19: The substrate was dissolved in THF and cooled to 0°C. TBAF (1.0 M solution in THF) was added (1.05 eq.) and the reaction monitored by TLC. After 30 min. at 0°C, the reaction was complete and the solvent was evaporated under reduced pressure. The crude material was applied to a short column of silica gel and eluted to give the product.

Synthesis of compound 1029 as illustrated in Figure 19: Compound 1028 was dissolved in 0.10 Molar solution of acetone and then 1.5 M sulfuric acid was added at 0 °C. Next chromium (VI) oxide (1.1 equivalents; Aldrich) was added and the mixture was allowed to stir for 2 hours. The reaction is worked up by adding EtOAc and washed with sat. NaHCO<sub>3</sub> solution, then with brine, dried over MgSO<sub>4</sub> and concentrated *in vacuo* to give an oil. The mother liquor is then chromatographed to give the product 1029.

Synthesis of compound 1030 as illustrated in Figure 19: The substrate 1029 (70 mg, 0.213 mmol), is dissolved in dry methylene chloride (3 mL). EDC, 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide, (43 mg, 0.224 mmol) is added and the mixture is stirred for 30 minutes at room temperature. *tert*-butyl amine (73 mg, 0.255 mmol) is added and the reaction stirred for 18 hours. The reaction mixture is diluted with ethyl acetate (20 mL) and added to saturated ammonium chloride (30 mL). The aqueous phase is extracted with ethyl acetate (3 x 10 mL). The combined organic phases are then washed with water (2 x 5 mL), 1 N HCl (aq.) (5 mL), saturated sodium bicarbonate solution (aq.) (50 mL), water (5 mL), brine (5 mL) and dried ( $MgSO_4$ ) before concentration in vacuo to give the crude product. Flash chromatography, eluting with 1:1 ethyl acetate/hexane gives the desired coupled product.

Synthesis of compound 42 as illustrated in Figure 19: CBZ-protected amine 1030 (0.092 mmol) was dissolved in MeOH (2 mL) and 20% palladium hydroxide on carbon (10 mg) was added and the suspension was stirred vigorously under a balloon of hydrogen at ambient temperature. After 5 min., TLC indicated that the reaction was complete. The suspension was filtered through a pad of celite and concentrated in vacuo to yield product compound 42.

Synthesis of compound 1032 as illustrated in Figure 20: Compound 1031 (290 mg, 1.09 mmol; Aldrich) in methylene chloride (0.10 Molar) at 0 °C under argon

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was added CBZ-Cl (1.1 equivalents; Aldrich) and the mixture was stirred at 0 °C for 20 min. and then quenched with a few drops of water. Saturated ammonium chloride solution was added (10 mL) and the aqueous layer was washed with ethyl ether. The aqueous layer was then neutralized with saturated sodium bicarbonate solution, extracted with ethyl acetate (3 x 20 mL), dried over MgSO<sub>4</sub>, and concentrated to afford a yellow oil. The mother liquor is then chromatographed to give the product. Next, to a solution of substrate (0.5 mmol) in anhydrous DMF (5 mL) was added TBDMSCl (1.05eq: Aldrich), Et<sub>3</sub>N (1.1 eq), and a catalytic amount of imidazole. The solution was stirred at ambient temperature for 15 hr and then was partitioned between EtOAc (60 mL) and H<sub>2</sub>O (30 mL). The organic layer was then washed with sat'd NH<sub>4</sub>Cl<sub>(aq.)</sub> solution (2 x 30 mL), water (30 mL), brine (30 mL), dried over MgSO<sub>4</sub>, and concentrated in vacuo to yield product. The mother liquor is then chromatographed to give the product 1032.

**Synthesis of compound 1033 as illustrated in Figure 20:** The substrate 1032 (70 mg, 0.213 mmol), is dissolved in dry methylene chloride (3 mL). EDC, 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide, (43 mg, 0.224 mmol) is added and the mixture is stirred for 30 minutes at room temperature. *tert*-butyl amine (73 mg, 0.255 mmol) is added and the reaction stirred for 18 hours. The reaction mixture is diluted with ethyl acetate (20 mL) and added to saturated ammonium chloride (30 mL). The aqueous phase is extracted with ethyl acetate (3 x 10 mL). The combined organic

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phases are then washed with water (2 x 5 mL), 1 N HCl (aq.) (5 mL), saturated sodium bicarbonate solution (aq.) (50 mL), water (5 mL), brine (5 mL) and dried ( $MgSO_4$ ) before concentration *in vacuo* to give  
5 the crude product. Flash chromatography, eluting with 1:1 ethyl acetate/hexane gives the desired coupled product.

**Synthesis of compound 1034 as illustrated in Figure 20:** The substrate was dissolved in THF and cooled to 0°C. TBAF (1.0 M solution in THF) was added (1.05 eq.) and the reaction monitored by TLC. After 30 min. at 0°C, the reaction was complete and the solvent was evaporated under reduced pressure. The 15 crude material was applied to a short column of silica gel and eluted to give the product.

**Synthesis of compound 1038 as illustrated in Figure 20:** Synthesis was carried out via a Mitsunobu inversion using identical conditions as published in Saiah et al. *Tet. Lett.* 1992, 33, 4317; Johnson et al *J. Am. Chem. Soc.* 1964, 86, 118. The reaction mixture is then worked up by dilution with ethyl acetate (20 mL) and is added to saturated ammonium chloride (30 mL). The aqueous phase is extracted with ethyl acetate (3 x 10 mL). The combined organic phases are then washed with water (2 x 5 mL), 1 N HCl (aq.) (5 mL), saturated sodium bicarbonate solution (aq.) (50 mL), water (5 mL), brine (5 mL) and dried ( $MgSO_4$ )  
25 before concentration *in vacuo* to give the crude product. Flash chromatography, eluting with 1:1 ethyl acetate/hexane gives the desired coupled product.  
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**Synthesis of compound 58 as illustrated in Figure 20:**

To the CBZ-protected amine (0.092 mmol) was dissolved  
in MeOH (2 mL) and 20% palladium hydroxide on carbon  
(10 mg) was added and the suspension was stirred  
vigorously under a balloon of hydrogen at ambient  
temperature. After 5 min., TLC indicated that the  
reaction was complete. The suspension was filtered  
through a pad of celite and concentrated in vacuo to  
yield product.

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**Synthesis of compound 59 as illustrated in Figure 20:**

CBZ-protected amine 1038 ( 0.092 mmol) was dissolved  
in MeOH (2 mL) and 20% palladium hydroxide on carbon  
(10 mg) was added and the suspension was stirred  
vigorously under a balloon of hydrogen at ambient

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temperature. After 5 min., TLC indicated that the  
reaction was complete. The suspension was filtered  
through a pad of celite and concentrated in vacuo to  
yield product. Next, to an ice-cooled solution of

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substrate (0.2 mmol) in anhydrous DMF (2 mL) under  
argon was added NaH (60% disp. in mineral oil) (2.2  
eq.). The mixture was allowed to stir for 20 min.,  
and then benzyl bromide (1.1 eq.) was added. The

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mixture was allowed to stir for 1 hr at 0°C and then  
quenched with a few drops of water. Saturated NaHCO<sub>3</sub>  
solution was added (10 mL) and the aqueous layer was  
washed with ethyl ether. The aqueous layer was then  
acidified to pH 2 with 1N HCl, extracted with ethyl  
acetate (3 x 20 mL), dried over MgSO<sub>4</sub>, and

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concentrated to afford product. The mother liquor is  
then chromatographed to give the product to give 58.

**Synthesis of compound 60 as illustrated in Figure 20:**

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To an ice-cooled solution of substrate **1038** (0.2 mmol) in anhydrous DMF (2 mL) under argon was added NaH (60% disp. in mineral oil) (2.2 eq.). The mixture was allowed to stir for 20 min., and then methyl iodide (1.1 eq.) was added. The mixture was allowed to stir for 1 hr at 0°C and then quenched with a few drops of water. Saturated NaHCO<sub>3</sub> solution was added (10 mL) and the aqueous layer was washed with ethyl ether. The aqueous layer was then acidified to pH 2 with 1N HCl, extracted with ethyl acetate (3 x 20 mL), dried over MgSO<sub>4</sub>, and concentrated to afford product. The mother liquor is then chromatographed to give the product to give intermediate product. Next, to the CBZ-protected amine (0.092 mmol) was dissolved in MeOH (2 mL) and 20% palladium hydroxide on carbon (10 mg) was added and the suspension was stirred vigorously under a balloon of hydrogen at ambient temperature. After 5 min., TLC indicated that the reaction was complete. The suspension was filtered through a pad of celite and concentrated in vacuo to yield product.

**Synthesis of compound 64 as illustrated in Figure 20:**  
To the CBZ-protected amine **1034** (0.092 mmol) was dissolved in MeOH (2 mL) and 20% palladium hydroxide on carbon (10 mg) was added and the suspension was stirred vigorously under a balloon of hydrogen at ambient temperature. After 5 min., TLC indicated that the reaction was complete. The suspension was filtered through a pad of celite and concentrated in vacuo to yield product.

**Synthesis of compound 65 as illustrated in Figure 20:**

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CBZ-protected amine **1034** (0.092 mmol) was dissolved in MeOH (2 mL) and 20% palladium hydroxide on carbon (10 mg) was added and the suspension was stirred vigorously under a balloon of hydrogen at ambient 5 temperature. After 5 min., TLC indicated that the reaction was complete. The suspension was filtered through a pad of celite and concentrated in vacuo to yield product. Next, to an ice-cooled solution of substrate (0.2 mmol) in anhydrous DMF (2 mL) under 10 argon was added NaH (60% disp. in mineral oil) (2.2 eq.). The mixture was allowed to stir for 20 min., and then benzyl bromide (1.1 eq.) was added. The mixture was allowed to stir for 1 hr at 0°C and then quenched with a few drops of water. Saturated NaHCO<sub>3</sub> 15 solution was added (10 mL) and the aqueous layer was washed with ethyl ether. The aqueous layer was then acidified to pH 2 with 1N HCl, extracted with ethyl acetate (3 x 20 mL), dried over MgSO<sub>4</sub>, and concentrated to afford product. The mother liquor is 20 then chromatographed to give the product to give **65**.

**Synthesis of compound 66 as illustrated in Figure 20:**  
To an ice-cooled solution of substrate **1034** (0.2 mmol) in anhydrous DMF (2 mL) under argon was added 25 NaH (60% disp. in mineral oil) (2.2 eq.). The mixture was allowed to stir for 20 min., and then methyl iodide (1.1 eq.) was added. The mixture was allowed to stir for 1 hr at 0°C and then quenched with a few drops of water. Saturated NaHCO<sub>3</sub> solution 30 was added (10 mL) and the aqueous layer was washed with ethyl ether. The aqueous layer was then acidified to pH 2 with 1N HCl, extracted with ethyl acetate (3 x 20 mL), dried over MgSO<sub>4</sub>, and

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concentrated to afford product. The mother liquor is then chromatographed to give the product to give intermediate product. Next, to the CBZ-protected amine (0.092 mmol) was dissolved in MeOH (2 mL) and  
5 20% palladium hydroxide on carbon (10 mg) was added and the suspension was stirred vigorously under a balloon of hydrogen at ambient temperature. After 5 min., TLC indicated that the reaction was complete. The suspension was filtered through a pad of celite  
10 and concentrated in vacuo to yield product.

Synthesis of compound 1040 as illustrated in Figure 21: Piperidine compound 1039 (290 mg, 1.09 mmol; Aldrich) in methylene chloride (0.10 Molar) at 0 °C under argon was added CBZ-Cl (1.1 equivalents; Aldrich) and the mixture was stirred at 0 °C for 20 min. and then quenched with a few drops of water. Saturated ammonium chloride solution was added (10 mL) and the aqueous layer was washed with ethyl ether. The aqueous layer was then neutralized with saturated sodium bicarbonate solution, extracted with ethyl acetate (3 x 20 mL), dried over MgSO<sub>4</sub>, and concentrated to afford a yellow oil. The mother liquor is then chromatographed to give the product.  
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Synthesis of compound 1041 as illustrated in Figure 21:

To a solution of substrate (0.5 mmol) in anhydrous DMF (5 mL) was added TBDPSCl (1.05eq: Aldrich), Et<sub>3</sub>N (1.1 eq), and a catalytic amount of imidazole. The solution was stirred at ambient temperature for 15 hr and then was partitioned between EtOAc (60 mL) and H<sub>2</sub>O (30 mL). The organic layer was then washed with

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sat'd NH<sub>4</sub>Cl<sub>(aq.)</sub> solution (2 x 30 mL), water (30 mL), brine (30 mL), dried over MgSO<sub>4</sub>, and concentrated in vacuo to yield product. The mother liquor is then chromatographed to give the product 1041.

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**Synthesis of compound 1042 as illustrated in Figure**

**21:** To an ice-cooled solution of substrate (0.2 mmol) in anhydrous DMF (2 mL) under argon was added NaH (60% disp. in mineral oil) (2.2 eq.). The mixture

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was allowed to stir for 20 min., and then methyl iodide or benzyl bromide (1.1 eq.) was added. The mixture was allowed to stir for 1 hr at 0°C and then quenched with a few drops of water. Saturated NaHCO<sub>3</sub> solution was added (10 mL) and the aqueous layer was washed with ethyl ether. The aqueous layer was then acidified to pH 2 with 1N HCl, extracted with ethyl acetate (3 x 20 mL), dried over MgSO<sub>4</sub>, and concentrated to afford product. The mother liquor is then chromatographed to give the product 1042.

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**Synthesis of compound 1043 as illustrated in Figure**

**21:** The substrate was dissolved in THF and cooled to 0°C. TBAF (1.0 M solution in THF) was added (1.05 eq.) and the reaction monitored by TLC. After 30

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min. at 0°C, the reaction was complete and the solvent was evaporated under reduced pressure. The crude material was applied to a short column of silica gel and eluted to give the product.

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**Synthesis of compound 1044 as illustrated in Figure**

**21:** Compound 1043 was dissolved in 0.10 Molar solution of acetone and then 1.5 M sulfuric acid was added at 0 °C. Next chromium (VI) oxide (1.1

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equivalents; Aldrich) was added and the mixture was allowed to stir for 2 hours. The reaction is worked up by adding EtOAc and washed with sat. NaHCO<sub>3</sub> solution, then with brine, dried over MgSO<sub>4</sub> and concentrated *in vacuo* to give an oil. The mother liquor is then chromatographed to give the product 1044.

Synthesis of compound 1045 as illustrated in Figure 21: The substrate 1044 (70 mg, 0.213 mmol), is dissolved in dry methylene chloride (3 mL). EDC, 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide, (43 mg, 0.224 mmol) is added and the mixture is stirred for 30 minutes at room temperature. *tert*-butyl amine (73 mg, 0.255 mmol) is added and the reaction stirred for 18 hours. The reaction mixture is diluted with ethyl acetate (20 mL) and added to saturated ammonium chloride (30 mL). The aqueous phase is extracted with ethyl acetate (3 x 10 mL). The combined organic phases are then washed with water (2 x 5 mL), 1 N HCl (aq.) (5 mL), saturated sodium bicarbonate solution (aq.) (50 mL), water (5 mL), brine (5 mL) and dried (MgSO<sub>4</sub>) before concentration *in vacuo* to give the crude product. Flash chromatography, eluting with 1:1 ethyl acetate/hexane gives the desired coupled product.

Synthesis of compounds 86 or 87 as illustrated in Figure 21: CBZ-protected amine 1045 (0.092 mmol) was dissolved in MeOH (2 mL) and 20% palladium hydroxide on carbon (10 mg) was added and the

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suspension was stirred vigorously under a balloon of hydrogen at ambient temperature. After 5 min., TLC indicated that the reaction was complete. The suspension was filtered through a pad of celite and concentrated in vacuo to yield product compound 86 or 87, depending on whether benzyl or methyl.

**Synthesis of compounds 1046 as illustrated in Figure 22:** Piperidine compound 1041 (290 mg, 1.09 mmol; Aldrich) in methylene chloride (0.10 Molar) at 0 °C under argon was added acetic anhydride (3.3 equivalents; Aldrich), triethyl amine (3.3 equivalents) and the mixture was stirred at 0 °C for 20 min. and then quenched with a few drops of water. Saturated ammonium chloride solution was added (10 mL) and the aqueous layer was washed with ethyl ether. The aqueous layer was then neutralized with saturated sodium bicarbonate solution, extracted with ethyl acetate (3 x 20 mL), dried over MgSO<sub>4</sub>, and concentrated to afford a yellow oil. The mother liquor is then chromatographed to give the product.

**Synthesis of compound 1047 as illustrated in Figure 22:** The substrate was dissolved in THF and cooled to 0°C. TBAF (1.0 M solution in THF) was added (1.05 eq.) and the reaction monitored by TLC. After 30 min. at 0°C, the reaction was complete and the solvent was evaporated under reduced pressure. The crude material was applied to a short column of silica gel and eluted to give the product.

**Synthesis of compound 1048 as illustrated in Figure 22:** Compound 1047 was dissolved in 0.10 Molar

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solution of acetone and then 1.5 M sulfuric acid was added at 0 °C. Next chromium (VI) oxide (1.1 equivalents; Aldrich) was added and the mixture was allowed to stir for 2 hours. The reaction is worked up by adding EtOAc and washed with sat. NaHCO<sub>3</sub> solution, then with brine, dried over MgSO<sub>4</sub> and concentrated *in vacuo* to give an oil. The mother liquor is then chromatographed to give the product.

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**Synthesis of compound 1049 as illustrated in Figure 22:** The substrate 1048 (70 mg, 0.213 mmol), is dissolved in dry methylene chloride (3 mL). EDC, 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide, (43 mg, 0.224 mmol) is added and the mixture is stirred for 30 minutes at room temperature. *tert*-butyl amine (73 mg, 0.255 mmol) is added and the reaction stirred for 18 hours. The reaction mixture is diluted with ethyl acetate (20 mL) and added to saturated ammonium chloride (30 mL). The aqueous phase is extracted with ethyl acetate (3 x 10 mL). The combined organic phases are then washed with water (2 x 5 mL), 1 N HCl (aq.) (5 mL), saturated sodium bicarbonate solution (aq.) (50 mL), water (5 mL), brine (5 mL) and dried (MgSO<sub>4</sub>) before concentration *in vacuo* to give the crude product. Flash chromatography, eluting with 1:1 ethyl acetate/hexane gives the desired coupled product. Compound is then redissolved in dry methanol (3 mL) and sodium methoxide (0.30 equivalents added and the mixture is stirred for 18 hours at reflux. The is concentrated *in vacuo* to give the crude product. Flash chromatography, eluting with 1:1 ethyl acetate/hexane gives the

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desired product 1049.

Synthesis of compounds 88 as illustrated in Figure 22: CBZ-protected amine 1049 (0.092 mmol) was dissolved in MeOH (2 mL) and 20% palladium hydroxide on carbon (10 mg) was added and the suspension was stirred vigorously under a balloon of hydrogen at ambient temperature. After 5 min., TLC indicated that the reaction was complete. The suspension was filtered through a pad of celite and concentrated in vacuo to yield product compound 88.

Synthesis of Compound 1050A as illustrated in Figure 27.

Step 1) To a solution of commercially available trans-3-hydroxyproline is added 1.1 equivalents BOC-ON (Aldrich) in a 1:1 v/v solution water/ dioxanes and NaOH (1N solution) and stirred at 0 °C for 12 hours. The combined organic phases are then washed with water (2 x 5 mL), 1 N HCl (aq.) (5 mL), saturated sodium bicarbonate solution (aq.) (50 mL), water (5 mL), brine (5 mL) and dried ( $\text{MgSO}_4$ ) before concentration in vacuo to give the crude product. Flash chromatography, eluting with 1:1 ethyl acetate/hexane gives the desired protected product.

Step 2) As illustrated in figure 27 the substrate (70 mg, 0.213 mmol; *vida supra*), is dissolved in dry methylene chloride (3 mL). EDC, 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide, (43 mg, 0.224 mmol) is added and the mixture is stirred for 30 minutes at room temperature. *tert*-butyl amine (73 mg, 0.255 mmol) is added and the reaction stirred for 18 hours. The reaction mixture is diluted with ethyl

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acetate (20 mL) and added to saturated ammonium chloride (30 mL). The aqueous phase is extracted with ethyl acetate (3 x 10 mL). The combined organic phases are then washed with water (2 x 5 mL), 1 N HCl (aq.) (5 mL), saturated sodium bicarbonate solution (aq.) (50 mL), water (5 mL), brine (5 mL) and dried ( $MgSO_4$ ) before concentration in vacuo to give the crude product. Flash chromatography, eluting with 1:1 ethyl acetate/hexane gives the desired product 1050A.

**Synthesis of Compound 1050B as illustrated in Figure 27.**

Step 1) To an ice-cooled solution of N-(benzyloxycarbonyl)-cis-3'-hydroxyproline (290 mg, 1.09 mmol; *vida supra*) in anhydrous DMF (2 mL) under argon was added NaH (60% disp. in mineral oil) (96 mg, 2.40 mmol, 2.2 eq.). The mixture was allowed to stir for 20 min., and then benzyl bromide (0.14 mL, 1.20 mmol, 1.1 eq.) was added. The mixture was allowed to stir for 1 hr at 0°C and then quenched with a few drops of water. Saturated  $NaHCO_3$  solution was added (10 mL) and the aqueous layer was washed with ethyl ether. The aqueous layer was then acidified to pH 2 with 1N HCl, extracted with ethyl acetate (3 x 20 mL), dried over  $MgSO_4$ , and concentrated to afford a yellow oil. (205 mg, 53%) The crude material was carried on without purification.

Step 2) To the crude yellow oil (0.982 mmol) was added TBAF (1M in THF) (1.9 mL, 1.9 mmol, 2 eq.), and the solution was stirred 2 hr at ambient temperature. The solution was concentrated in vacuo and

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immediately applied to a short silica gel column, eluting with 33% ethyl acetate in hexanes. The product was isolated as a white foam (443 mg, 95%).

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**Synthesis of Compound 1050 as illustrated in Figure 27.**

As illustrated in figure 13, steps i-ii, the substrate 11 (70 mg, 0.213 mmol), is dissolved in dry DMF (3 mL). HOBT, 1-hydroxybenzotriazole hydrate (31 mg, 0.22 mmol), EDC, 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide, (43 mg, 0.224 mmol), DIEA, diisopropylethylamine, (122  $\mu$ L, 0.703 mmol) are added and the mixture is stirred for 30 minutes at room temperature. The secondary amine 1050B (73 mg, 0.255 mmol) is added and the reaction stirred for 18 hours. The reaction mixture is diluted with ethyl acetate (20 mL) and added to saturated ammonium chloride (30 mL). The aqueous phase is extracted with ethyl acetate (3  $\times$  10 mL). The combined organic phases are then washed with water (2  $\times$  5 mL), 1 N HCl (aq.) (5 mL), saturated sodium bicarbonate solution (aq.) (50 mL), water (5 mL), brine (5 mL) and dried ( $MgSO_4$ ) before concentration *in vacuo* to give the crude product. Flash chromatography, eluting with 1:1 ethyl acetate/hexane gives the desired coupled product which is directly carried on to the next step for oxidation of the secondary alcohol as follows. The secondary alcohol (21 mg, 0.044 mmol) is dissolved in dry  $CH_2Cl_2$  (2 mL), and Dess-Martin periodinane (26 mg, 0.088 mmol) added. The reaction mixture is stirred at ambient temperature for 24 hours, then diluted with ethyl acetate (10 mL) and

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quenched by addition of saturated sodium bicarbonate (aq.) (5 mL) and sodium thiosulfate. The aqueous phase is extracted with ethyl acetate (3 x 20 mL).  
5 The combined organic extracts washed with water (10 mL), brine (10 mL), dried ( $MgSO_4$ ) and concentrated *in vacuo* to give the crude product. Flash chromatography eluting with 30% ethyl acetate in hexane gives the respective product 1050 as a 3:1 mixture of diastereomers (colorless oil) (20 mg, 95%)  
10 as a colorless oil.

15 **Synthesis of *N*-benzyl-*cis*-and *trans*-2,5-dicarb-methoxy-pyrrolidines Compound 1051A (Figure 28):** *N*-benzyl-*cis*-and *trans*-2,5-dicarbmethoxypyrrolidine were synthesized according to the procedure of Cignarella and Nathansohn (Cignarella, G. Nathansohn, G., *JOC*, 1961, 26, 1500.) The two diastereomers (cis and trans) were separated by flash chromatography (1:9 EA/H to 1:4 EA/H). Analytical data matched that reported by Kemp and Curran (Kemp, D.S., Curran, T.P. *JOC*, 1988, 53, 5729)

20 **Synthesis of Cis-(2S,5R)-dicarbmethoxypyrollidine (Step 1, intermediate to compound 1051B (figure 28)):**  
25 *N*-benzyl-*cis*-(2S, 5R)-dicarbmethoxypyrrolidine (1.0 equivalents) was dissolved in MeOH (0.10 M) and a catalytic amount of 10% palladium on carbon was added. The mixture was stirred vigorously under a balloon of hydrogen until TLC indicated that the reaction was complete. Filtration and concentration afforded a clean product.  
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**Synthesis of N-(benzyloxycarbonyl)-dimethyl pyrrolidine-(2S,5R)-dicarboxylate (Step 2, intermediate to compound 1051B (figure 28)):** To the crude substrate dimethyl pyrrolidine-2,5-dicarboxylate (869 mg, 4.06 mmol) was added water (20 mL). The solution was cooled to 0 °C in an ice bath, and 0.3 M K<sub>2</sub>CO<sub>3</sub> was added dropwise until pH = 9. CbzCl (1.1 eq, 4.5 mmol) was added and the mixture was stirred 30 min at 0°C and 30 min at ambient temperature. The aqueous layer was extracted with EtOAc (3 x 20 mL) and was dried over MgSO<sub>4</sub>, filtered, and concentrated under reduced pressure to yield a yellow oil. Purification by flash chromatography (1:3 EA/ H) yielded a clear oil. (1.2 g) Rf (1:1 EA/ H) = 0.48.

**Synthesis of N-(benzyloxycarbonyl)-cis-(2S,5R)-dimethanol pyrrolidine compound 1051B:** The substrate N-(benzyloxycarbonyl)-dimethyl pyrrolidine-(2S, 5R)-dicarboxylate (766 mg, 2.3 mmol) was dissolved in anhydrous THF (15 mL) and the solution was cooled to -78 °C in a dry ice/acetone bath. To this solution was added DIBAL-H (1.5 M in toluene) (14.2 mL, 9.6 mmol, 4.2 eq.). The solution was allowed to stir at -78°C, and gradually warmed to 0 °C during the course of 1 hr. The reaction was then quenched with 1N HCl (a few drops), and THF removed in vacuo. The slurry was extracted with EtOAc (3 x 30 mL) and washed with brine (30 mL). After drying over MgSO<sub>4</sub> and concentrated in vacuo to yield a yellow oil. Flash column purification in 1:1 EA/ H gave the desired diol.

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Synthesis of N-(benzyloxycarbonyl)-cis-(2S)-methanol-(5R)-(butyroxymethyl) pyrrolidine (Step 1, intermediate to compound 1051C (figure 28)): The substrate diol (800 mg, 3.02 mmol) was dissolved in vinyl butyrate (10 mL), and 553 mg of Lipase AK was added. The reaction was stirred slowly at ambient temperature until TLC indicated that starting material was gone. (60 hr.). The reaction mixture was diluted with CH<sub>2</sub>Cl<sub>2</sub>, filtered through Celite, and concentrated. After flash chromatography eluting with a gradient of 1:4 to 1:1 ethyl acetate in hexanes, the product was isolated as a colorless oil. (675 mg, 67% yield, 85% ee) (The enantiomeric excess was determined by conversion to the Mosher ester followed by <sup>19</sup>F NMR analysis).

Synthesis of N-(benzyloxycarbonyl)-5-cis-(butyroxymethyl)-L-proline compound 1051C (figure 28). To an ice cooled solution of CrO<sub>3</sub> (6.83 mmol, 3.75 eq.) in 1.5M H<sub>2</sub>SO<sub>4</sub> (aq.) (9 mL) was added substrate (611 mg, 1.82 mmol) in acetone (30 mL + 10 mL wash). The resulting orange solution was stirred vigorously at 0°C for 30 min., and then at ambient temperature for 7 hrs. Ethyl ether (40 mL) was then added and the organic layer was washed with brine solution (20 mL), dried over MgSO<sub>4</sub>, and concentrated in vacuo to afford crude product. This product which was subjected to a short column of silica eluting with 100% ethyl acetate to give pure product as a colorless oil (571 mg, 89%) <sup>1</sup>H NMR (CD<sub>3</sub>OD, 250 MHz) (peaks broadened by rotamers) δ = 7.45-7.20 (5H, m), 5.25-4.90 (3H, m), 4.40-4.25 (1H, m), 4.25-4.00 (3H, m), 2.38-2.15 (2H, m), 2.15-1.73 (4H, m), 1.72-1.42

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(2H, m), 1.00-0.78 (3H, m);  $^{13}\text{C}$  NMR ( $\text{CD}_3\text{OD}$ )  $\delta$  = 175.7, 174.9, 156.4, 156.0, 137.6, 129.5, 129.3, 129.2, 129.0, 128.8, 128.5, 128.4, 68.3, 68.1, 65.4, 65.0, 61.3, 60.9, 58.6, 58.1, 36.7, 29.9, 28.9, 28.1, 19.2, 13.9; FABHRMS (NBA) m/e 350.1593 ([M + H]<sup>+</sup> C<sub>18</sub>H<sub>23</sub>NO<sub>6</sub> requires 350.1604.

**Synthesis of N-(Benzylloxycarbonyl)-5-cis-(butyroxymethyl)-L-proline-tert-butyl amide compound**

1051D (figure 28): The substrate i (13.9 mmol) was dissolved in dry  $\text{CH}_2\text{Cl}_2$  (20 mL). HOBT, 1-hydroxybenzotriazole hydrate (2.07 g, 15.3 mmol), EDC, 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide, (2.93 g, 15.3 mmol), and tert-butylamine (1.6 mL, 15.3 mmol), were added and the mixture stirred for 18 hours at ambient temperature. The reaction was diluted with ethyl acetate (100 mL), and washed with water (2 x 20 mL), 1 N HCl (aq.) (10 mL), saturated sodium bicarbonate solution (aq.) (10 mL), water (10 mL), brine (10 mL) and dried ( $\text{MgSO}_4$ ) before concentration *in vacuo* to give the crude product. Purification by flash chromatography, eluting with 33% EtOAc in Hexane gave the title compound as a colorless oil.

25

**Synthesis of N-(Benzylloxycarbonyl)-5-cis-hydroxymethyl-L-proline-tert-butyl amide compound**

1052A (intermediate en route to compound 1051E (figures 28 and 29)): The substrate was dissolved in MeOH:  $\text{H}_2\text{O}$  (8 mL: 4 mL) and cooled to 0°C. LiOH was added (128 mg, 5.0 eq.) and the mixture stirred for 20 min. at 0°C. The mixture was neutralized with 1N HCl and then extracted into EtOAc, dried over  $\text{MgSO}_4$ ,

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and filtered to afford product which was used in the next step without purification.

5           **Synthesis of 5-cis-hydroxymethyl-L-proline-tert-butyl amide (compound 1051E (figure 28)):** Intermediate compound 1052A (1.0 equivalents; *vida supra*) was dissolved in MeOH (0.10 M) and a catalytic amount of 10% palladium on carbon was added. The mixture was stirred vigorously under a balloon of hydrogen until  
10           TLC indicated that the reaction was complete. Filtration and concentration afforded a clean product.

15           **Synthesis of compound 1051 (figure 28)** Using the general procedure as follows: To the pyrrolidine derivative 1051 E (20 mg, 0.091 mmol) was added dry methanol (2 mL), Cbz-phenylalanyl epoxide 21 (27 mg, 0.091 mmol, 1.0 eq; *vida supra*) and triethylamine (14  $\mu$ L, 0.100mmol, 1.1eq.). The solution was refluxed for 32 h, and then concentrated *in vacuo*. Flash chromatography, eluting with ethyl acetate provides the desired product as a clear oil.

25           **Synthesis of N-(Benzylloxycarbonyl)-5-cis-(tert-butyl-dimethyl-silyl-oxyethyl)-L-proline-tert-butyl amide (intermediate to compound 1052B; (figure 29))** A solution of N-(benzylloxycarbonyl)-5-cis-hydroxymethyl-L-proline-tert-butyl amide 1052A (81 mg, 0.24 mmol; *vida supra*) in CH<sub>2</sub>Cl<sub>2</sub> (3 mL) was cooled to 0°C under an argon bed. 2,6-lutidine (0.48 mL, 56 mL, 2.0eq.) and tert-butyl dimethylsilyl triflate (88 mL, 0.38 mmol, 1.6 eq.) were added subsequently. After stirring for 1

hr at 0°C, the reaction was quenched by pouring the reaction mixture into an ice cold mixture of sat'd NaHCO<sub>3</sub> (aq) solution: H<sub>2</sub>O (5 mL: 25 mL) and extracting into CH<sub>2</sub>Cl<sub>2</sub> (3 x 20 mL). The pooled organic layers were washed with 10% CuSO<sub>4</sub> (aq) solution (2 x 20mL), dried over MgSO<sub>4</sub>, filtered, and evaporated under reduced pressure. Flash chromatography eluting with 25% ethyl acetate in hexanes gave the intermediate compound as a colorless oil (85mg, 79%). R<sub>f</sub> = 0.58 (1:1 EtOAc/ Hexanes). <sup>1</sup>H NMR (CDCl<sub>3</sub>, 250 MHz) (peaks broadened by rotamers) δ = 7.33-7.26 (5H, m), 5.14 (2H, br s), 4.18-4.12 (1H, m), 4.08-3.90 (1H, m), 3.83-3.71 (2H, m), 2.39-2.00 (2H, m), 2.00-1.82 (2H, m), 1.24 (9H, s), 0.86 (9H, s), 0.03 (6H, br s); <sup>13</sup>C NMR (CDCl<sub>3</sub>, 62.5 MHz) 136.1, 128.4, 128.1, 127.9, 67.2, 64.3, 50.7, 28.4, 25.9; FABHRMS (NBA) m/e 581.1824 ([M + Cs]<sup>+</sup> C<sub>24</sub>H<sub>40</sub>N<sub>2</sub>O<sub>4</sub>Si requires 581.1822. Intermediate compound (1.0 equivalents; *vida supra*) was dissolved in MeOH (0.10 M) and a catalytic amount of 10% palladium on carbon was added. The mixture was stirred vigorously under a balloon of hydrogen until TLC indicated that the reaction was complete. Filtration and concentration afforded a clean product to give 1052B.

25

Synthesis of 2S,3S)-3-(N-Benzylloxycarbonyl)amino-2-hydroxy-4-phenylbutyryl-5'-cis-(tert-butylidimethylsilyloxyethyl)-L-prolyl-tert-butyl amide (intermediate en route to compound 1052; figure 29, step 1) α-Hydroxy acid 11 (62.5 mg, 0.19 mmol, 1.0 eq; *vida supra*), EDC (40 mg, 1.1 eq.), HOBT (28.2 mg, 1.1 eq.) were stirred in dry DMF (1 mL) at

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ambient temperature, under argon. After  
preativation for 30 min., the amine 1052B (59 mg,  
1.0 eq) dissolved in dry DMF (0.5 mL + 2 x 0.5 mL  
washes) was cannulated into the activated acid  
5 mixture. After stirring for 12 hr, the reaction  
mixture was concentrated in vacuo, and EtOAc was  
added. The organic layer was washed with water (2 x  
5 mL), dried over MgSO<sub>4</sub>, and solvent removed under  
reduced pressure. Flash chromatography eluting with  
10 20% ethyl acetate in hexanes gave intemediate as a  
white crystalline solid (77mg, 65%). R<sub>f</sub>= 0.59 (1:2  
EtOAc/ Hexanes); <sup>1</sup>H NMR (CDCl<sub>3</sub>, 400MHz): (mixture of  
two rotamers) δ = 7.32-7.09 (20H, m), 6.86 (1H, s),  
6.42 (1H, s), 5.63 (1H, d, J= 8.9 Hz), 5.42 (1H, d,  
15 J= 8.8 Hz), 5.07 (1H, d, J=12.0 Hz), 5.00 (1H, d, J=  
12.0 Hz), 5.08-4.92 (2H, m), 4.53-4.38 (2H, m), 4.37-  
4.19 (3H, m), 4.12-3.97 (3H, m), 3.89-3.71 (2H, m),  
3.63-3.52 (1H, m), 3.52-3.47 (1H, m), 2.90-2.62 (4H,  
m), 2.50-2.32 (1H, m), 2.20-1.60 (9H, m), 1.30 (9H,  
20 s), 1.27 (9H, s), 0.87 (9H, s), 0.86 (9H, s), 0.08  
(3H, s), 0.06 (3H, s), 0.04 (3H, s), 0.01 (3H, s);  
<sup>13</sup>C NMR (CDCl<sub>3</sub>, 100MHz); FABHRMS (NBA) m/e  
758.2618([M + Cs]<sup>+</sup> C<sub>34</sub>H<sub>51</sub>N<sub>3</sub>O<sub>6</sub>Si requires 758.2601.

25 **Synthesis of intermediate to compound 1052 (step 2,  
figure 29) General Dess-Martin Oxidation**  
Procedure: (2S,3S)-3-(N-Benzylloxycarbonyl)amino-2-  
keto-4-phenylbutyryl-5'-cis-(tert-  
butyldimethylsilyloxyethyl)-L-prolyl-tert-butyl  
30 amide

The substrate X (28 mg, 0.044 mmol) was dissolved in  
dry CH<sub>2</sub>Cl<sub>2</sub> (2 mL) and Dess-Martin periodinane (26 mg,  
0.088 mmol, 2.0 eq.) was added. The reaction mixture

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was stirred at ambient temperature for 24 hr, then  
diluted with ethyl acetate (10 mL), and quenched by  
addition of sat'd sodium bicarbonate(aq.) (5 mL), and  
5 sodium thiosulfate. The aqueous phase was extracted  
with ethyl acetate (3 x 20 mL). The combined organic  
extracts were washed with water (10 mL), dried over  
MgSO<sub>4</sub>, and concentrated in vacuo to give the crude  
product. Flash chromatography eluting with 50% ethyl  
acetate in hexanes gave the desired product as a  
10 white solid (1:1 mixture of diastereomers). (26 mg,  
95%) R<sub>f</sub> = 0.47 (1:2 EtOAc/ Hexanes); 1H NMR (CDCl<sub>3</sub>,  
400MHz); δ = 7.36-7.13 (20 H, m), 6.40 (1H, s), 6.07  
(1H, s), 5.36 (1H, d, J= 7.2 Hz), 5.18 (1H, d, J= 6.8  
Hz), 5.11-4.97 (5h, m), 4.96-4.90 (1H, m), 4.50-4.47  
15 (1H, m), 4.22-4.18 (2H, m), 3.99 (1H, dd, J= 9.6, 4.9  
Hz), 3.96-3.87 (1H, m), 3.75 (1H, dd, J= 10.0, 4.8  
Hz), 3.53-3.32 (3H, m), 3.27 (1H, dd, J= 14.2, 5.5  
Hz), 3.18 (1H, dd, J= 14.1, 8.1 Hz), 2.91 (1H, dd, J=  
14.0, 9.7 Hz), 2.40-2.28 (1H, m), 2.25-2.16 (1H, m),  
20 2.08-1.97 (1H, m), 1.96-1.78 (2H, m), 1.72-1.52 (3H,  
m), 1.34 (9H, s), 1.31 (9H, s), 0.88 (9H, s), 0.86  
(9H, s), 0.09 (3H, s), 0.06 (3H, s), 0.04 (3H, s),  
0.03 (3H, s); <sup>13</sup>C (CDCl<sub>3</sub>, 100MHz); IR (NaCl) ν<sub>max</sub>  
3332.3, 2955.0, 2856.0, 2358.1, 1714.7, 1634.1,  
25 1537.8, 1454.8, 1258.0, 1094.6; FABHRMS (NBA) m/e  
756.2469 ([M + Cs]<sup>+</sup> C<sub>34</sub>H<sub>49</sub>N<sub>3</sub>O<sub>6</sub>Si requires 756.2445.

Synthesis of compound 1052 (as illustrated in figure  
29): To a 1.0 Molar solution of 1.0 equivalents  
30 substrate, TBAF (1.0 M solution in THF) was added  
(0.34 mL, 1.05 eq.) and the reaction monitored by  
TLC. After 30 min. at 0°C, the reaction was complete  
and the solvent was evaporated under reduced

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pressure. The crude material was applied to a short column of silica gel and eluted with 33% hexanes in ethyl acetate to give a yellow oil (162 mg, 94%)

5           **Synthesis of N-(Benzylloxycarbonyl)-5-cis-(methoxymethyl)-L-proline-tert-butyl amide compound 1053A (figure 29).** A solution of 1052A (156 mg, 0.467 mmol) in anhydrous DMF (3 mL) was cooled to 0°C under argon. NaH, 60% disp. in mineral oil, (28.0 mg, 0.70 mmol, 1.5 eq.) was added and the suspension was allowed to stir for 20 min. Iodomethane (116 mL, 1.8 mmol, 4.0 eq.) was then added and the mixture stirred for 3 hr at 0°C. The reaction was quenched by addition of a few drops of 1N HCl(aq.) solution, and then diluted with H<sub>2</sub>O (10 mL). The aqueous layer was extracted with EtOAc (3 x 20 mL), dried over MgSO<sub>4</sub>, filtered, and evaporated under reduced pressure. Flash chromatography eluting with 50% ethyl acetate in hexanes gave an intermediate as a colorless oil (146 mg, 89%). R<sub>f</sub> = 0.25 (1:1 EtOAc/ Hexanes). <sup>1</sup>H NMR (CDCl<sub>3</sub>) <sup>13</sup>C NMR (CDCl<sub>3</sub>, MHz) FABHRMS (NBA) m/e 349.2119 ([M+ H]<sup>+</sup> C<sub>19</sub>H<sub>28</sub>N<sub>2</sub>O<sub>4</sub> requires 349.21270  
To a solution of above intermediate (85 mg, 0.19 mmol) in MeOH (3 mL) was added a catalytic amount of 10% Pd/C and the mixture stirred under a balloon of H<sub>2</sub> at ambient temperature. After 20 min, TLC indicated that the reaction was complete and the mixture was filtered through a bed of Celite and washed with MeOH. Removal of solvent under reduced pressure gave a colorless oil (89mg, quant.) as compound 1053A which was used in the next step without further purification. <sup>1</sup>H NMR (CDCl<sub>3</sub>, 400MHz)

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d = 5.64 (1H, br s), 4.21 (1H, dd, J= 9.2, 5.0 Hz),  
3.78-3.68 (1H, m), 3.53 (1H, dd, 9.8, 4.1Hz), 3.46-  
3.37 (1H, m), 3.42 (3H, s), 2.41-2.31 (m, 1H), 2.06-  
1.89 (2H, m), 1.69-1.60 (1H, m), 1.36 (9H, s). 13C  
5 (CDCl<sub>3</sub>, 100 MHz) d 171.2, 73.4, 60.2, 59.2, 59.0,  
51.0, 30.7, 28.6, 27.0. FABHRMS (NBA) m/e 215.1764  
([M + H]<sup>+</sup> C<sub>11</sub>H<sub>22</sub>N<sub>2</sub>O<sub>2</sub> requires 215.1760.

10           **Synthesis of (2S,3S)-3-(N-Benzylloxycarbonyl)amino-2-hydroxy-4-phenylbutyryl-5'-cis-(methoxymethyl)-L-prolyl-tert-butyl amide (intermediate to compound 1053, figure 29)**

15           Synthesized according to the General Coupling Procedure outlined above and as illustrated in synthesis of compound 1052 (figure 29). Rf= 0.30 (EtOAc: Hexanes 1:2) 1H NMR (CDCl<sub>3</sub>, 400 MHz): (mixture of rotamers) d = 7.33-7.17 (20 H, m), 6.91 (2H, d, J= 5.6 Hz), 5.75 (1H, d, J= 8.8 Hz), 5.64 (1H, d, J= 8.8 Hz), 5.07 (1H, d, J=12.3 Hz), 5.03 (2H, s), 4.91 (1H, d), 4.61-4.55 (1H, m), 4.53-4.38 (3H, m), 4.28-4.15 (4H, m), 4.02-3.95 (1H, m), 3.93-3.86 (2H, m), 3.81-3.75 (1H, m), 3.46 (1H, d, J= 8.7 Hz), 3.39-3.26 (3H, m), 3.35 (3H, s), 3.20 (3H, s), 2.93-2.84 (3H, m), 2.80-2.73 (1H, m), 2.42-2.35 (1H, m), 2.15-1.82 (3H, m), 1.80-1.74 (1H, m), 1.72-1.62 (1H, m), 1.30 (9H, s), 1.27 (9H, s); 13C NMR (CDCl<sub>3</sub>, 100MHz) d =172.4, 171.6, 171.1, 169.9, 156.2, 156.0, 137.6, 137.2, 136.4, 136.2, 129.5, 129.4, 129.1, 128.5, 128.4, 128.3, 128.2, 128.0, 127.9, 127.8, 30 127.7, 126.9, 126.4, 73.2, 71.2, 71.0, 70.2, 66.6, 66.4, 61.8, 60.8, 60.7, 60.4, 59.5, 59.0, 58.8, 58.7 58.0, 55.3, 54.7, 54.5, 51.1, 50.8, 35.1, 29.8, 29.6, 28.5, 27.9, 26.2, 24.1, 21.0, 14.1; FABHRMS (NBA) m/e

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658.1879 ([M + Cs]<sup>+</sup> C<sub>29</sub>H<sub>39</sub>N<sub>3</sub>O<sub>6</sub> requires 658.1893.

Synthesis of (2S,3S)-3-(N-Benzylloxycarbonyl)amino-2-keto-4-phenylbutyryl-5'-cis-(methoxymethyl)-L-prolyl-  
5 tert-butyl amide (compound 1053; figure 29)

Synthesized according to the General Dess-Martin procedure as noted above and as illustrated in the example for compound 1052 (figure 29). R<sub>f</sub> = 0.40  
(1:1 EtOAc/ Hexanes); 1H NMR (CDCl<sub>3</sub>, 400 MHz) (1:1  
10 mixture of diastereomers) δ = 7.33-7.16 (20H, m),  
6.88 (1H, s), 6.79 (1H, s), 5.70 (1H, d, J = 8.6 Hz),  
5.26 (1H, d, J = 7.1 Hz), 5.18-5.12 (2H, m), 5.08-  
4.92 (4H, m), 4.48-4.43 (2H, m), 4.28-4.22 (1H, m),  
4.14-4.10 (1H, m), 4.09-4.02 (1H, m), 3.45 (1H, dd, J  
15 = 9.5, 1.9 Hz), 3.37 (3H, s), 3.36-3.17 (6H, m), 3.15  
(3H, s), 2.94 (1H, dd, J = 13.9, 9.4 Hz), 2.42-2.30  
(1H, m), 2.20-2.10 (1H, m), 2.08-1.82 (5H, m), 1.81-  
1.72 (1H, m), 1.34 (9H, s), 1.30 (9H, s); <sup>13</sup>C  
(CDCl<sub>3</sub>, 100MHz); 198.0, 197.0, 171.1, 169.4, 164.9,  
20 163.9, 155.9, 155.6, 136.3, 136.1, 129.7, 129.3,  
128.7, 128.5, 128.4, 128.3, 128.1, 127.0, 126.8,  
74.3, 70.4, 67.1, 66.8, 63.6, 61.2, 59.8, 58.8, 58.6,  
58.5, 57.9, 57.6, 51.0, 50.9, 37.2, 29.9, 28.6, 27.4,  
25 25.7, 24.9; IR (NaCl) ν<sub>max</sub> 3331.1, 2966.8, 2340.9,  
1717.4, 1646.2, 1540.6, 1455.8, 1252.9, 1111.7,  
1047.1; FABHRMS (NBA) m/e 656.1714 ([M + Cs]<sup>+</sup>  
C<sub>29</sub>H<sub>37</sub>N<sub>3</sub>O<sub>6</sub> requires 656.1737; (Found C, 66.24; H,  
7.21; N, 7.78; C<sub>29</sub>H<sub>37</sub>N<sub>3</sub>O<sub>6</sub> requires C, 66.50, H, 7.13;  
N, 8.03).  
30 5.

Synthesis of para-(ortho-nitrobenzyl oxy)-hydroxybenzyl bromide compound 1054A as illustrated

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in figure 30

Step 1) To a solution of para-hydroxybenzyl alcohol (2.0 g, 16.1 mmol; Aldrich) dissolved in dry acetone (15 mL) was added K<sub>2</sub>CO<sub>3</sub> (4.45 g, 32.2 mmol, 2.0 eq.) and ortho-nitrobenzylbromide (3.83 g, 17.7 mmol, 1.1 eq.). The mixture was stirred at ambient temperature for 16 hr and then the solution was concentrated in vacuo. The residue was taken up in EtOAc (100 mL) and then the organic layer was washed with H<sub>2</sub>O (2 x 30 mL), brine (30 mL) and dried over MgSO<sub>4</sub>. The product was recrystallized from Et<sub>2</sub>O/hexanes to give yellow needles (2.0 g, 60%) of para-(ortho-nitrobenzyl)-hydroxybenzyl alcohol. <sup>1</sup>H NMR (CDCl<sub>3</sub>, 400 MHz) δ = 8.16 (1H, dd, J = 8.2, 1.3 Hz), 7.88 (1H, dd, 7.9, 1.0 Hz), 7.68 (1H, dt, J = 7.5, 1.2 Hz), 7.51-7.46 (1H, m), 7.32-7.26 (2H, m), 6.98-6.95 (2H, m), 5.48 (2H, s), 4.61 (2H, s); <sup>13</sup>C NMR (CDCl<sub>3</sub>, 100 MHz) δ = 157.6, 133.9, 128.7, 128.5, 128.2, 124.9, 114.8, 66.8, 64.9;

Step 2) To a suspension of Ph<sub>3</sub>P (1.03 g, 3.94 mmol, 1.02 eq.) in CH<sub>3</sub>CN (10 mL) cooled to 0°C. Bromine (0.20 mL, 3.86 mmol, 1.0 eq.) was added dropwise. The ice bath was then removed and a solution of para-(ortho-nitrobenzyl)hydroxybenzyl alcohol in 5mL of CH<sub>3</sub>CN was added via cannulation. After stirring for 10 min., the CH<sub>3</sub>CN was removed in vacuo and the residue was extracted with hexanes (5 x 30mL) and filtered through a pad of Celite. Concentration of the hexanes in vacuo yielded a fluffy white solid compound 1054A (1.1g, 88%); <sup>1</sup>H NMR (CDCl<sub>3</sub>, 400 MHz) δ = 8.17 (1H, d, J = 8.2 Hz), 7.86 (1H, d, J = 7.8 Hz), 7.68 (1H, t, J = 7.4 Hz), 7.54-7.49 (1H, m), 7.34 (2H, d, J = 8.4 Hz), 6.94 (2H, d, J = 8.4 Hz), 5.49

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(2H, s), 4.50 (2H, s);

Synthesis of trans-3'-(tert-butyldimethylsilyloxy) L-proline tert-butyl amide compound 1054C as  
5 illustrated in Figure 30

To a solution of N-(benzyloxycarbonyl)-trans-3'-hydroxyproline tert-butyl amide 1054B (739 mg, 2.31 mmol; *vida supra*; synthesized as 1050A, figure 27) in anhydrous DMF (10mL) was added TBDMSCl (366 mg, 2.42 mmol, 1.05eq), Et<sub>3</sub>N (0.35 mL, 2.54 mmol, 1.1 eq), and a catalytic amount of DMAP. The solution was stirred at ambient temperature for 15 hr and then was partitioned between EtOAc (60 mL) and H<sub>2</sub>O (30 mL). The organic layer was then washed with sat'd NH<sub>4</sub>Cl(aq.) solution (2 x 30 mL), water (30 mL), brine (30 mL), dried over MgSO<sub>4</sub>, and concentrated in vacuo to yield the crude material as a yellow oil. The yellow oil was then dissolved in MeOH (20 mL) and a catalytic amount of 10% Pd/C was added. The mixture was stirred vigorously under a balloon of H<sub>2</sub> for 1 hr. The mixture was then filtered through Celite and concentrated in vacuo to yield a yellow oil (690 mg, 99 %); <sup>1</sup>H NMR (CDCl<sub>3</sub>, 400 MHz) δ = 6.97 (1H, s), 4.46 (1H, dd, J = 9.1, 4.6 Hz), 3.76 (1H, d, J = 4.04 Hz), 3.42 (1H, dt, J = 10.6, 7.6 Hz), 3.21 (1H, ddd, J = 10.6, 7.5, 5.8 Hz), 1.34 (9H, s), 0.89 (9H, s), 0.12 (3H, s), 0.11 (3H, s); <sup>13</sup>C NMR (CDCl<sub>3</sub>, 100 MHz) δ = 168.3, 75.5, 67.8, 51.4, 44.1, 33.8, 28.6, 25.7, -4.6, -4.8; FABHRMS (NBA) m/e 301.2317 ([M + H]<sup>+</sup> C<sub>15</sub>H<sub>32</sub>N<sub>2</sub>O<sub>2</sub>Si requires 301.2311);

Synthesis of (2S,3S)-3-N-(benzyloxycarbonyl)-amino-2-hydroxy-4-phenylbutyryl-trans-3'-(tert-

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butyldimethylsilyloxy)-L-prolyl-tert-butyl amide compound 1054D as illustrated in figure 30.

Synthesized according to the general peptide coupling procedure outlined above as exemplified for compound

5       **1052, figure 29.**     <sup>1</sup>H NMR (CDCl<sub>3</sub>, 400 MHz) δ = 7.28-  
7.08 (10H, m), 6.48 (1H, s), 5.57 (1H, d, J = 8.8  
Hz), 5.08-4.93 (2H, m), 4.63-4.58 (1H, m), 4.52-4.38  
(1H, m), 4.26 (1H, br s), 4.20-3.61 (4H, m), 1.24  
(9H, s), 0.88 (9H, s), 0.09 (6H, s); <sup>13</sup>C NMR (CDCl<sub>3</sub>,  
10      100 MHz) δ = 171.4, 170.0, 168.5, 156.6, 156.1,  
137.4, 136.2, 135.9, 129.1, 128.8, 128.4, 128.0,  
127.9, 127.4, 126.4, 73.1, 71.6, 71.2, 69.7, 69.2,  
66.6, 66.5, 54.8, 54.5, 51.4, 51.3, 45.9, 45.5, 34.5,  
33.6, 32.9, 31.8, 28.5, 28.4, 25.7, 17.9, 14.1;

15       **Synthesis of (2S,3S)-3-N-(benzyloxycarbonyl)-amino-2-acetoxy-4-phenylbutyryl-trans-3'-(tert-butyldimethylsilyloxy)-L-prolyl-tert-butyl amide intermediate compound to 1054E as illustrated in figure 30.** To a solution of (2S,3S)-3-N-(benzyloxycarbonyl)-amino-2-hydroxy-4-phenylbutyryl-trans-3'-(tert-butyldimethylsilyloxy)-L-prolyl-tert-butyl amide 1054D (216 mg, 0.35 mmol) in anhydrous CH<sub>2</sub>Cl<sub>2</sub> was added acetic anhydride (67 mL, 0.71 mmol, 2.0 eq.), pyridine (71 mL, 0.882 mmol, 2.5 eq.). It was difficult to tell whether the reaction had gone to completion by monitoring by TLC, since the R<sub>f</sub> values of the starting material and product were virtually identical. After stirring the reaction for 15 hr under argon, EtOAc (40 mL) was added and the solution was washed with sat'd NH<sub>4</sub>Cl(aq.) (20 mL), sat'd NaCO<sub>3</sub> (aq.) (20 mL), water (20 mL) and brine (20 mL). The organic layer was dried over MgSO<sub>4</sub>,

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filtered, and concentrated to yield a white fluffy solid. (211 mg, 92%);  $^1\text{H}$  NMR (CDCl<sub>3</sub>, 400 MHz)  $\delta$  = 7.33- 7.13 (10H, m), 6.47 (1H, s), 5.57 (1H, d), 5.36-5.30 (1H, m), 5.02 (2H, s), 4.69-4.58 (1H, m), 5  
4.39-4.31 (1H, m), 4.20-4.09 (1H, m), 3.87-3.57 (2H, m), 2.98-2.79 (2H, m), 2.26-2.22 (1H, m), 2.08 (3H, s), 1.95-1.85 (1H, m), 1.31 (9H, s), 0.87 (9H, s), 0.099 (6H, s);  $^{13}\text{C}$  NMR (CDCl<sub>3</sub>, 100 MHz)  $\delta$  = 170.2, 169.9, 168.6, 167.8, 167.4, 166.5, 155.9, 136.9, 10  
136.1, 128.9, 128.5, 128.4, 128.0, 127.8, 127.7, 126.6, 76.5, 73.3, 72.8, 71.3, 69.5, 69.4, 66.7, 66.5 5  
52.7, 52.4, 51.4, 51.1, 45.5, 45.2, 35.5, 34.3, 33.8, 31.0, 28.5, 28.2, 25.6, 25.5, 20.5, 20.3, 17.9, 17.6; FABHRMS (NBA) m/e 786.2571 ([M + Cs]<sup>+</sup> C<sub>35</sub>H<sub>51</sub>N<sub>3</sub>O<sub>7</sub>Si requires 786.2551);

Synthesis of (2S,3S)-3-N-(benzyloxycarbonyl)-amino-2-acetoxy-4-phenylbutyryl-trans-3'-hydroxy-L-prolyl-tert-butyl amide compound 1054E as illustrated in figure 30. The substrate (2S,3S)-3-N-(benzyloxycarbonyl)-amino-2-acetoxy-4-phenylbutyryl-trans-3'-(tert-butyldimethylsilyloxy)-L-prolyl-tert-butyl amide (1.0 equivalents; *vida supra*) was dissolved in THF and cooled to 0°C. TBAF (1.0 M solution in THF) was added (0.34 mL, 1.05 eq.) and the reaction monitored by TLC. After 30 min. at 0°C, the reaction was complete and the solvent was evaporated under reduced pressure. The crude material was applied to a short column of silica gel and eluted with 33% hexanes in ethyl acetate to give a yellow oil (162 mg, 94%)

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Synthesis of (2S,3S)-3-N-(benzyloxycarbonyl)-amino-2-hydroxy-4-phenylbutyryl-trans-3'-(para-(ortho-nitrobenzyl)benzyloxy)-L-prolyl-tert-butyl amide compound 1054F, figure 30.

- 5 To a solution of (2S,3S)-3-N-(benzyloxycarbonyl)-amino-2-acetoxy-4-phenylbutyryl-trans-3'-hydroxy-L-prolyl-tert-butyl amide dissolved in anhydrous THF (3 mL) was added para-(ortho-nitrobenzyl)hydroxybenzylbromide (106.4 mg, 0.331 mmol), 4A molecular sieves (spatula-full), and silver triflate (a spatula-full). The reaction was complete in 10 minutes at ambient temperature so it was immediately filtered through a pad of Celite and washed with Et<sub>2</sub>O. After flash chromatography eluting with 50% ethyl acetate in hexanes, a colorless oil was isolated (165 mg, 70%).
- 10 The substrate (2S,3S)-3-(N-Benzylloxycarbonyl)amino-2-acetoxy-4-phenylbutyryl-3'-trans-[para-(ortho-nitrobenzyl)benzyloxy]-L-prolyl-tert-butyl amide was dissolved in MeOH: H<sub>2</sub>O (7 mL: 1 mL) and cooled to 0°C. K<sub>2</sub>CO<sub>3</sub> (146 mg, 1.06 mmol, 5.0 eq.) was added and the cloudy mixture was allowed to warm gradually to RT. Monitoring the reaction by TLC was difficult because the starting material and product had nearly identical R<sub>f</sub> values. The reaction was stirred at RT for an additional 30 min., and then the MeOH was removed in vacuo. The resulting residue was partitioned between water (20 mL) and EtOAc (30 mL) and dried over MgSO<sub>4</sub>, filtered, and concentrated to yield a colorless oil (155 mg, 99%).
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Synthesis of (2S,3S)-3-N-(benzyloxycarbonyl)-amino-2-keto-4-phenylbutyryl-trans-3'-(para-

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hydroxybenzyloxy]-L-prolyl-tert-butyl amide compound 1054. Step 1) Synthesized according to the general Dess-Martin oxidation procedure as outlined above for compound 1052, figure 29.

5 Step 2) The substrate (2S,3S)-3-N-(benzyloxycarbonyl)-amino-2-keto-4-phenylbutyryl-trans-3'-(para-(ortho-nitrobenzyloxy)benzyloxy]-L-prolyl-tert-butyl amide was dissolved in CH<sub>2</sub>Cl<sub>2</sub> (1 mL) and placed in the sunlight until TLC indicated that  
10 the reaction had gone to completion. The solution was concentrated in vacuo and purified by flash chromatography (eluent 33% ethyl acetate in hexanes) to yield a slightly yellow oil.

15 Alternative compounds 1059, 1060 and other hydroxybenzyloxyproline substituted  $\alpha$ -keto amides. The synthesis of the trans-3-meta-hydroxybenzyloxyproline substituted  $\alpha$ -keto amides is done in an analogous fashion to that described above for the trans-3-para-hydroxybenzyl-substituted system; 1059 and 1060 can be synthesized using the bromides shown in figure 30.

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**Synthesis of N-(benzyloxycarbonyl)-cis-4'-(benzyloxy)-L-proline succinate ester compound 1055A** as illustrated in figure 31. Step 1) To an ice-cooled solution of N-(benzyloxycarbonyl)-cis-4'-hydroxyproline (290 mg, 1.09 mmol; Aldrich) in anhydrous DMF (2 mL) under argon was added NaH (60% disp. in mineral oil) (96 mg, 2.40 mmol, 2.2 eq.). The mixture was allowed to stir for 20 min., and then benzyl bromide (0.14 mL, 1.20 mmol, 1.1 eq.) was added. The mixture was allowed to stir for 1 hr at

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5      0°C and then quenched with a few drops of water. Saturated NaHCO<sub>3</sub> solution was added (10 mL) and the aqueous layer was washed with ethyl ether. The aqueous layer was then acidified to pH 2 with 1N HCl, extracted with ethyl acetate (3 x 20 mL), dried over MgSO<sub>4</sub>, and concentrated to afford a yellow oil. (205 mg, 53%) The crude material was carried on without purification.

Step 2) To a solution of N-(benzyloxycarbonyl)-cis-4'-(benzyloxy)-L-proline (41 mg, 0.115 mmol) in anhydrous CH<sub>2</sub>Cl<sub>2</sub> (2 mL) was added EDC (68 mg, 0.356 mmol, 3.1 eq.) and N-hydroxysuccinimide (40 mg, 0.345 mmol, 3.0 eq.). The solution was stirred for 2 hrs. The solvent was removed, and the residue was partitioned between ethyl ether and water (10 mL/ 5 mL). The water layer was extracted with ethyl ether and the combined organic layers were washed with brine (10 mL) and dried over MgSO<sub>4</sub>. Concentration followed by flash chromatography eluting with 9% methanol in ethyl acetate yielded the desired product as a white solid (51 mg, 98%) <sup>1</sup>H NMR (CDCl<sub>3</sub>, 400MHz) (two distinct rotamers, only major rotamer noted here) d 7.38-7.25 (10H, m), 5.23 (1H, d, J = 12.4 Hz, ab-Cbz), 5.10 (1H, d, 12.4 Hz ab-Cbz), 4.75 (1H, dd, J = 9.4, 3.0 Hz, a-H), 4.63 (1H, d J = 12.5 Hz, ab-Bn), 4.48 (1H, d, J = 12.5 Hz, ab-Bn), 4.15-4.09 (1H, m, CH-OBn), 3.75-3.62 (2H, m, NCH<sub>2</sub>CHO Bn), 2.82 (4H, s, succ.CH<sub>2</sub>), 2.65-2.62 (1H, m, NCH<sub>2</sub>CHO BnCH<sub>2</sub>), 2.47-

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Synthesis of N-(benzyloxycarbonyl)-cis--4'-(benzyloxy)-L-proline-isoleucine-glutamine-tert-butyl ester compound 1055B. To a solution of N-

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(benzyloxycarbonyl)-*cis*-4'-(benzyloxy)-L-proline succinate ester 1055A (28 mg, 0.0619 mmol) in anhydrous CH<sub>2</sub>Cl<sub>2</sub> (2 mL) was added the dipeptide H<sub>2</sub>N-Ile-Gln-(OtBu ester) (39 mg, 0.123 mmol, 2 eq.) and the solution was stirred at ambient temperature for 45 min. The solution was diluted with CH<sub>2</sub>Cl<sub>2</sub> (5 mL) and then washed with sat'd NH<sub>4</sub>Cl solution (5 mL), sat'd NaHCO<sub>3</sub> solution, brine (5 mL) and dried over MgSO<sub>4</sub>. Concentration followed by flash chromatography with 8% methanol in ethyl acetate afforded the desired product as a white solid (40 mg, 99%). <sup>1</sup>H NMR (CDCl<sub>3</sub>, 400 MHz) δ = 7.36-7.27 (10H, m), 6.99 (1H, br s), 6.84 (1H, d, J = 8.6 Hz), 6.75 (1H, br s), 5.80 (1H, br s), 5.15 (2H, s), 4.53-4.32 (4H, m), 4.33-4.30 (1H, m), 4.12-4.09 (1H, m), 3.71 (1H, d, J = 11.9 Hz), 3.59-3.54 (1H, m), 2.64-2.61 (1H, m), 2.30-2.15 (4H, m), 2.00-1.85 (1H, m), 1.83-1.69 (1H, m), 1.53-1.38 (2H, m), 1.45 (9H, s), 1.00-0.93 (1H, m), 0.81-0.71 (6H, m); <sup>13</sup>C NMR (CDCl<sub>3</sub>, 100 MHz) δ 175.2, 171.2, 170.5, 156.2, 137.4, 135.9, 81.9, 76.4, 70.5, 67.7, 60.6, 57.8, 53.4, 52.1, 36.7, 34.1, 31.7, 28.1, 24.5, 15.0, 11.2; FABHRMS (NBA) m/e 785.2520 ([M + Cs]<sup>+</sup> C<sub>35</sub>H<sub>48</sub>N<sub>4</sub>O<sub>8</sub> requires 785.2526);

Synthesis of *cis*-4-(benzyloxy)-L-proline-isoleucine-glutamine-tert-butyl ester compound 1055C as illustrated in figure 31.

To a solution of N-(benzyloxycarbonyl)-*cis*-4'-(benzyloxy)-L-proline-isoleucine-glutamine-tert-butyl ester 1055B (60 mg, 0.092 mmol) in MeOH (2 mL) was added 20% palladium hydroxide on carbon (10 mg) and the suspension was stirred vigorously under a balloon of hydrogen at ambient temperature. After 5 min.,

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TLC indicated that the reaction was complete. The suspension was filtered through a pad of celite and concentrated in vacuo to yield X (47 mg, quant.) 1H NMR (CD<sub>3</sub>OD, 400 MHz) δ 7.33-7.23 (5H, m), 4.47 (1H, d, J=11.8 Hz), 4.41 (1H, d, J=11.8 Hz), 4.27-4.18 (2H, m), 4.17-4.13 (1H, m), 3.88 (1H, dd, J=7.8, 4.3 Hz), 3.20 (1H, d, J=11.7 Hz), 3.12 (1H, dd, J=11.7, 4.6 Hz), 2.36-2.17 (2H, m), 2.12-2.07 (1H, m), 1.92-1.75 (2H, m), 1.57-1.46 (1H, m), 1.49 (9, s), 1.16-1.05 (1H, m), 0.92-0.88 (3H, m), 0.85-0.75 (3H, m); 13C NMR (CD<sub>3</sub>OD, 100 MHz) δ 177.4, 175.3, 173.3, 172.1, 139.6, 129.4, 128.9, 128.6, 82.9, 79.9, 71.9, 60.4, 59.0, 54.0, 53.0, 38.4, 37.1, 32.1, 32.5, 28.2, 25.8, 15.9, 11.5;

Synthesis of (2S,3S)-3-N-(benzyloxycarbonyl)-amino-2-keto-4-phenylbutyryl-cis-4'-benzyloxy-L-proline-isoleucine-glutamine-tert-butyl ester compound 1055 as illustrated in Figure 31. The following substances were combined in a flask, under a bed of argon: α-hydroxy acid 11 (26 mg, 0.080 mmol, 1.2 eq.), amine 1055C (35 mg, 0.067 mmol), HBTU (30.5 mg, 0.080 mmol, 1.2 eq.), and HOBT (10.9 mg, 0.080 mmol, 1.2 eq.). Anhydrous THF (1 mL) was added, followed by DIEA (28 mL, 0.161 mmol, 2.4 eq.) and the solution was stirred for 18hr at ambient temperature. After removal of the solvent in vacuo, the resulting residue was taken up in EtOAc (10 mL) and washed with sat'd NH<sub>4</sub>Cl(aq) (2 x 5 mL), sat'd NaHCO<sub>3</sub>(aq) (2 x 5 mL), water (1 x 5 mL), and brine (1 x 5 mL). The organic layer was then dried over MgSO<sub>4</sub>, filtered, and concentrated in vacuo to yield a crude yellow oil. After subjecting the crude oil to flash

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chromatography in 5% MeOH in  $\text{CH}_2\text{Cl}_2$ , a white solid was isolated (24 mg, 43% yield).  $R_f = 0.33$  (9:1  $\text{CH}_2\text{Cl}_2$ ).  
5  $^1\text{H}$  NMR ( $\text{CDCl}_3$ , 400 MHz) (major rotamer only)  $d = 7.33-7.11$  (15H, m), 7.11 (1H, d,  $J = 8.4$  Hz), 6.78 (1H, d,  $J = 10.2$  Hz), 6.71 (1H, s), 5.12 (1H, d,  $J = 12.5$  Hz), 4.89 (1H, d,  $J = 12.5$  Hz), 4.67-4.55 (1H, m), 4.55 (1H, d  $J = 12.5$  Hz), 4.50 (1H, d,  $J = 12.5$  Hz), 4.48-4.29 (3H, m), 4.19-4.03 (2H, m), 4.02-4.92 (1H, m), 3.74-3.66 (1H, m), 3.07 (2H, d,  $J = 7.4$  Hz), 2.52 (1H, d,  $J = 14.3$  Hz), 2.32-2.06 (4H, m), 2.05-1.86 (1H, m), 1.71-1.52 (1H, m), 1.42 (9H, s), 1.06-0.89 (1H, m), 0.83-0.59 (6H, m);  $^{13}\text{C}$  NMR ( $\text{CDCl}_3$ , 100 MHz)  $d = 175.5$ , 173.4, 171.5, 170.5, 170.4, 156.6, 137.9, 137.7, 137.1, 136.3, 129.2, 129.1, 128.5, 128.4, 127.9, 127.8,  
10 127.7, 126.5, 82.1, 76.5, 71.6, 70.7, 66.5, 60.8, 57.8, 56.2, 53.1, 52.2, 37.0, 34.4, 33.3, 31.7, 27.9, 25.0, 24.6, 14.9, 10.9.  
Step 2) The final product was obtained using the general Dess-Martin oxidation procedure as outlined  
15 above for compound 1052, figure 29 to produce compound 1055.

Synthesis of Compound 1056 as illustrated in figure 32. The following extended peptide isostere was synthesized on solid phase resin (MBHA) using standard peptide coupling conditions. The peptide was synthesized starting from the C-terminal end. *N*-BOC-Threonine was coupled to the resin (DCC, HOBT, DIEA), followed by deprotection of the amino group (TFA), and thorough washings with DMF and  $\text{CH}_2\text{Cl}_2$ . This standard coupling/ deprotection/ washing procedure was repeated seven times with the following *N*-BOC amino acids: (Gln, Ile, Pro, Phe ( $\alpha$ -hydroxy acid,  
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Ala, Gln, Pro). Subsequent Dess-Martin oxidation was performed while the peptide was still bound to the solid support. The resin-bound peptide was suspended in CH<sub>2</sub>Cl<sub>2</sub>, and Dess-Martin periodinane was added (2.0 eq). The resin was washed with copious amounts of water and MeOH through a fritted funnel. This procedure was repeated to ensure complete oxidation to the  $\alpha$ -keto-amide.

5                   Cleavage of the peptide from the solid support was done in the standard anhydrous HF apparatus, and

10                  purified by reverse phase HPLC

15                  **Synthesis of 2(R),5(R)-Bis(hydroxymethyl)-3(R),4(S)-dihydroxy-N-(benzyloxycarbonyl)-pyrrolidine-2,3-benzylidene acetal compound 1057C Figure 33.** To the substrate 2(R), 5(R)-Bis(hydroxymethyl)-3(R), 4(S)-dihydroxy-N-(benzyloxycarbonyl)-pyrrolidine (267 mg, 0.90 mmol; synthesized according to the procedure in Slee et al. *J. Am. Chem. Soc.*, 1995, 117, 11867)

20                  dissolved in anhydrous DMF (1 mL) was added benzaldehyde dimethyl acetal (242 mL, 1.62 mmol, 1.8 eq.). A catalytic amount of pTSA was added and the solution was allowed to stir under argon for 6 hr, after which the solution was partitioned between H<sub>2</sub>O (30 mL) and EtOAc (30 mL), and the aqueous layer was extracted with EtOAc (2 x 30 mL). The pooled organic layers were washed with brine (20 mL), dried over MgSO<sub>4</sub>, filtered, and concentrated to yield a crude yellow oil. Subsequent flash column purification, eluting with 50% ethyl acetate in hexanes yielded a white foam 1057C (246 mg, 71%).

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**Synthesis of compound 1057D as illustrated in Figure**

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33.

Step 1) To the 2(R), 5(R)-Bis(hydroxymethyl)-3(R),4(S)-dihydroxy-N-(benzyloxycarbonyl)-pyrrolidine-2,3-benzylidene acetal compound 1057C

5 (784 mg, 2.04 mmol) in anhydrous DMF (4 mL) was added TBDMSCl (316 mg, 2.09 mmol, 1.02 eq.), triethylamine (310 mL, 2.24 mmol, 1.1 eq.), and a catalytic amount of DMAP. The solution was stirred under argon for 18 hr, and then the solution was partitioned between

10 EtOAc (40 mL) and H<sub>2</sub>O (30 mL). The aqueous layer was extracted with EtOAc (2 x 40 mL), and the organic layers were washed with sat'd NH<sub>4</sub>Cl (aq.) (30 mL), brine (30 mL), dried over MgSO<sub>4</sub>, filtered, and concentrated in vacuo to yield a crude yellow oil.

15 (914 mg, 90%)

Step 2) The crude yellow oil was redissolved in 5 mL of anhydrous DMF (5 mL), and the solution was cooled to 0°C in an ice bath. NaH (52 mg, 2.16 mmol, 2.2 eq.), and benzyl bromide (0.128 mL, 1.08 mmol, 1.1 eq.) were added and the mixture was allowed to stir at 0°C for 1 hr. The reaction was quenched with sat'd NH<sub>4</sub>Cl (5 mL), and then EtOAc (40 mL) was added. The organic layer was washed with sat'd NaHCO<sub>3</sub> (aq.) (30 mL), water (2 x 30 mL), and brine (30 mL). After drying over MgSO<sub>4</sub>, filtration, and concentration in vacuo, the crude product was isolated as a yellow oil

30 .  
Synthesis of compound 1057E as illustrated in Figure  
33.

Step 1) To the crude yellow oil (0.982 mmol) was added TBAF (1M in THF) (1.9 mL, 1.9 mmol, 2 eq.), and the solution was stirred 2 hr at ambient temperature.

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The solution was concentrated in vacuo and immediately applied to a short silica gel column, eluting with 33% ethyl acetate in hexanes. The product was isolated as a white foam (443 mg, 95%).

5 Step 2) The white foam (0.191 mmol) was dissolved in CH<sub>2</sub>Cl<sub>2</sub> (1 mL) and Dess Martin periodinane (112 mg, 2.0 mmol, 2.0 eq.) was added. After 1 hr, sodium thiosulfate (500 mg) and H<sub>2</sub>O (30 mL) were added, and the aqueous layer was extracted with EtOAc (3 x 30 mL), dried over MgSO<sub>4</sub>, filtered, and concentrated to yield a crude product which was dissolved in tert-butanol (2.5 mL). To this solution, 2-methyl-2-butene (2M solution) (2 mL) was added and then a solution of sodium chlorite (199 mg, 1.75 mmol, 9.2 eq.) and NaH<sub>2</sub>PO<sub>4</sub> (354 mg, 1.32 mmol, 6.9 eq.) in H<sub>2</sub>O (1 mL) was added dropwise to the stirring substrate solution. After 1 hr, TLC indicated that the reaction was complete and the volatiles were removed in vacuo, and then remaining aqueous layer was extracted with diethyl ether (3 x 20 mL).

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Synthesis of Compound 1057 F as illustrated in Figure 33. As illustrated in figure 33 the substrate 1057E (70 mg, 0.213 mmol), is dissolved in dry methylene chloride (3 mL). EDC, 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide, (43 mg, 0.224 mmol) is added and the mixture is stirred for 30 minutes at room temperature. tertbutyl amine (73 mg, 0.255 mmol) is added and the reaction stirred for 18 hours. The reaction mixture is diluted with ethyl acetate (20 mL) and added to saturated ammonium chloride (30 mL). The aqueous phase is extracted with ethyl acetate (3

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x 10 mL). The combined organic phases are then washed with water (2 x 5 mL), 1 N HCl (aq.) (5 mL), saturated sodium bicarbonate solution (aq.) (50 mL), water (5 mL), brine (5 mL) and dried ( $\text{MgSO}_4$ ) before concentration *in vacuo* to give the crude product. Flash chromatography, eluting with 1:1 ethyl acetate/hexane gives the desired coupled product

- 10      **Synthesis of Compound 1057G as illustrated in Figure 33.** Reductive cleavage of the benzylidene ring is done using 1.1 equivalents DIBAL in 1.0 THF solution at 0 °C for 1 hour. The reaction mixture is diluted with ethyl acetate (20 mL) and added to saturated ammonium chloride (30 mL). The aqueous phase is extracted with ethyl acetate (3 x 10 mL). The combined organic phases are then washed with water (2 x 5 mL), 1 N HCl (aq.) (5 mL), saturated sodium bicarbonate solution (aq.) (50 mL), water (5 mL), brine (5 mL) and dried ( $\text{MgSO}_4$ ) before concentration *in vacuo* to give the crude product. Flash chromatography, eluting with 1:1 ethyl acetate/hexane gives the desired product
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- 25      **Synthesis of Compound 1057H as illustrated in Figure 33.** Deprotection of the Cbz group will be achieved selectively (in the presence of benzyl groups) using 0.10 equivalents palladium hydroxide on carbon, as described in the procedure above for compound 1055C, Figure 31.
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**Synthesis of Compound 1057 as illustrated in Figure 33.**

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As illustrated in figure 33, CB-Phe( $\alpha$ -OH) 11 (70 mg, 0.213 mmol), is dissolved in dry DMF (3 mL). HOBT, 1-hydroxybenzotriazole hydrate (31 mg, 0.22 mmol), EDC, 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide, (43 mg, 0.224 mmol), DIEA, diisopropylethylamine, (122  $\mu$ L, 0.703 mmol) are added and the mixture is stirred for 30 minutes at room temperature. The secondary amine 1057H (73 mg, 0.255 mmol) is added and the reaction stirred for 18 hours. The reaction mixture is diluted with ethyl acetate (20 mL) and added to saturated ammonium chloride (30 mL). The aqueous phase is extracted with ethyl acetate (3 x 10 mL). The combined organic phases are then washed with water (2 x 5 mL), 1 N HCl (aq.) (5 mL), saturated sodium bicarbonate solution (aq.) (50 mL), water (5 mL), brine (5 mL) and dried ( $MgSO_4$ ) before concentration *in vacuo* to give the crude product. Flash chromatography, eluting with 1:1 ethyl acetate/hexane gives the desired coupled product which is directly carried on to the next step for oxidation of the secondary alcohol as follows. The secondary alcohol (21 mg, 0.044 mmol) is dissolved in dry  $CH_2Cl_2$  (2 mL), and Dess-Martin periodinane (26 mg, 0.088 mmol) added. The reaction mixture is stirred at ambient temperature for 24 hours, then diluted with ethyl acetate (10 mL) and quenched by addition of saturated sodium bicarbonate (aq.) (5 mL) and sodium thiosulfate. The aqueous phase is extracted with ethyl acetate (3 x 20 mL). The combined organic extracts washed with water (10 mL), brine (10 mL), dried ( $MgSO_4$ ) and concentrated *in vacuo* to give the crude product. Flash chromatography eluting with 30% ethyl acetate in

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hexane gives the respective product 1057 as a 3:1 mixture of diastereomers (colorless oil) (20 mg, 95%) as a colorless oil.

5       Synthesis of N-(benzyloxycarbonyl)-3,4-didehydro-L-proline ethyl ester compound 1058C as illustrated in Figure 34. Synthesized according to the procedure from J. Org. Chem. 1994, 59, 5192.

10      Synthesis of N-(benzyloxycarbonyl)-(3R,4S)-dihydroxy-L-proline ethyl ester compound 1058D as illustrated in Figure 34.

To a solution of substrate (600 mg, 2.18 mmol) in *t*-butanol/ H<sub>2</sub>O (10 mL: 10 mL) was added AD-mix-b (3.0g) and methanesulfonamide (290 mg, 3.05 mmol, 1.4 eq.), and reaction was stirred at 4°C for 48 hr. The aqueous phase is extracted with ethyl acetate (3 x 20 mL). The combined organic extracts washed with water (10 mL), brine (10 mL), dried (MgSO<sub>4</sub>) and concentrated *in vacuo* to give the crude product. Flash chromatography eluting with 30% ethyl acetate in hexane gives the respective product 1058D as a colorless oil.

25      Synthesis of N-(benzyloxycarbonyl)-(3R,4S)-dihydroacetal-L-proline ethyl ester compound 1058E as illustrated in Figure 34. To the crude mixture of cis and trans - dihydroxy-L-proline ethyl ester was added acetone (10 mL), pTsA (a spatula-full), and CuSO<sub>4</sub> (spatula-full) and the mixture was refluxed and stirred for 24 h to give the corresponding acetonides. The aqueous phase is extracted with ethyl

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acetate (3 x 20 mL). The combined organic extracts washed with water (10 mL), brine (10 mL), dried (MgSO<sub>4</sub>) and concentrated *in vacuo* to give the crude product. Flash chromatography eluting with 30% ethyl acetate in hexane gives the respective product 1058E as a colorless oil.

Synthesis of (3R,4S)-dihydroacetal-L-proline tert-butyl amide compound 1058F as illustrated in Figure 34

As illustrated in figure 34 the substrate 1058E (70 mg, 0.213 mmol), is dissolved in dry methylene chloride (3 mL). EDC, 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide, (43 mg, 0.224 mmol) is added and the mixture is stirred for 30 minutes at room temperature. *tert*-butyl amine (73 mg, 0.255 mmol) is added and the reaction stirred for 18 hours. The reaction mixture is diluted with ethyl acetate (20 mL) and added to saturated ammonium chloride (30 mL). The aqueous phase is extracted with ethyl acetate (3 x 10 mL). The combined organic phases are then washed with water (2 x 5 mL), 1 N HCl (<sub>aq.</sub>) (5 mL), saturated sodium bicarbonate solution (<sub>aq.</sub>) (50 mL), water (5 mL), brine (5 mL) and dried (MgSO<sub>4</sub>) before concentration *in vacuo* to give the crude product. Flash chromatography, eluting with 1:1 ethyl acetate/hexane gives the desired coupled product Step 2) The product was dissolved in MeOH (0.10 M) and a catalytic amount of 10% palladium on carbon was added. The mixture was stirred vigorously under a balloon of hydrogen until TLC indicated that the reaction was complete. Filtration and concentration afforded a clean product 1058F.

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**Synthesis of compound 1058 as illustrated in Figure  
34**

To the pyrrolidine derivative 1058F (20 mg, 0.091 mmol) was added dry methanol (2 mL), Cbz-phenylalanyl epoxide 21 (27 mg, 0.091 mmol, 1.0 eq.) and triethylamine (14  $\mu$ L, 0.100mmol, 1.1eq.). The solution was refluxed for 32 h, and then concentrated *in vacuo*. Flash chromatography, eluting with ethyl acetate provides the desired product as a clear oil to give respectively hydroxylethyl amine derivative 1058.

**Preparation, Assay and Inhibition Analysis of the HIV  
Protease**

Plasmid pLAC-PRO 6.5 which contains the lacZ-protease fusion construct under the control of the rac promoter (composed of the *E. coli* ribosomal RNA promoter fused to lac operator) was prepared and transformed to *E. coli* JM103. To induce lacZ-pro synthesis, overnight culture of JM103 harboring pLAC-PRO 6.5 (PRO 6-5) was diluted 50 fold with LB broth containing 300 g/mL ampicillin. Cells were grown at 37°C for 1 h to  $A_{600} = 0.2-0.3$ , lactose (0.4% final concentration) was then added to induce the synthesis of lacZ-protease fusion protein. After overnight growth, cells were harvested by centrifugation in a Sorvall GSA rotor at 6,000 rpm for 7 minutes. Cell paste from 250 mL culture was suspended in 10 mL lysis buffer (50 mM Tris, 2 mM EDTA, 2 mM DTT, 100 mM NaCl, pH 7.5) containing 200 g/mL lysozyme and stood at 4°C overnight. The cell suspension was

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subsequently sonicated over a salted ice bath for 10 times with 10-15 pulses each at the maximal power output of the sonifier (Branson 450). Care was taken during sonication to keep the temperature of cell suspension below 10°C. The sonicates were then centrifuged at 6k rpm in a GSA rotor for 10 minutes. The majority of the *lacZ-pro* fusion proteins were found in the pellet. The insoluble *lacZ-pro* proteins were solubilized and unfolded in an aqueous solution containing 8M urea, and 50 mM dithiothreitol (DTT) or 1% 2-mercaptoethanol at concentrations of 0.2 mg/mL to 0.4 mg/mL. To refold the *lacZ-pro* proteins, the protein suspension were diluted with 12 volumes of 10 mM Tris at pH 6.0 and incubated at room temperature overnight (final protein concentration at 15 g/mL to 30 g/mL). Under these conditions, the *lacZ-pro* proteins underwent auto-proteolysis to yield the mature 10 kDa protease.

The renatured *lacZ*-protease fusion protein mixture was prepared as described above and freeze-dried in a lyophilizer overnight, resuspended in H<sub>2</sub>O, and dialyzed against 10 mM Tris buffer at pH 8.0 overnight to remove urea. Under these conditions the mature HIV protease forms an insoluble precipitate and can be readily purified by low speed centrifugation at 2,000xg for 20 min. The precipitated protease was redissolved in 8M urea, 10 mM Tris, pH 8.0, 1 mM DTT and passed through a DEAE-Sephacel column or a Pharmacia monoQ column in the same buffer. The flow through fraction was collected and dialyzed against 10 mM Tris, pH 8.0, 1 mM DTT, and concentrated by lyophilization. Both SDS gel electrophoresis and immunoblot analysis and amino

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acid analysis showed homogeneity of the protease. This procedure routinely gave 2-3 mg of the mature protease per gram of *E. coli* cells.

The synthetic HIV-protease containing a  
5 thioester linkage available from CalBiochem (San Diego) can also be used. The enzyme activity was assayed with the fluorogenic substrate Ac-Thr-Ile-Nle-Phe(*P*-NO<sub>2</sub>)-Gln-Arg-NH<sub>2</sub> (from CalBiochem, San Diego) according to the procedure described in the  
10 literature. Inhibition analysis was performed in the presence of the inhibitor and expressed with IC<sub>50</sub> (the concentration of inhibitor that causes 50% inhibition of the enzyme activity).

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